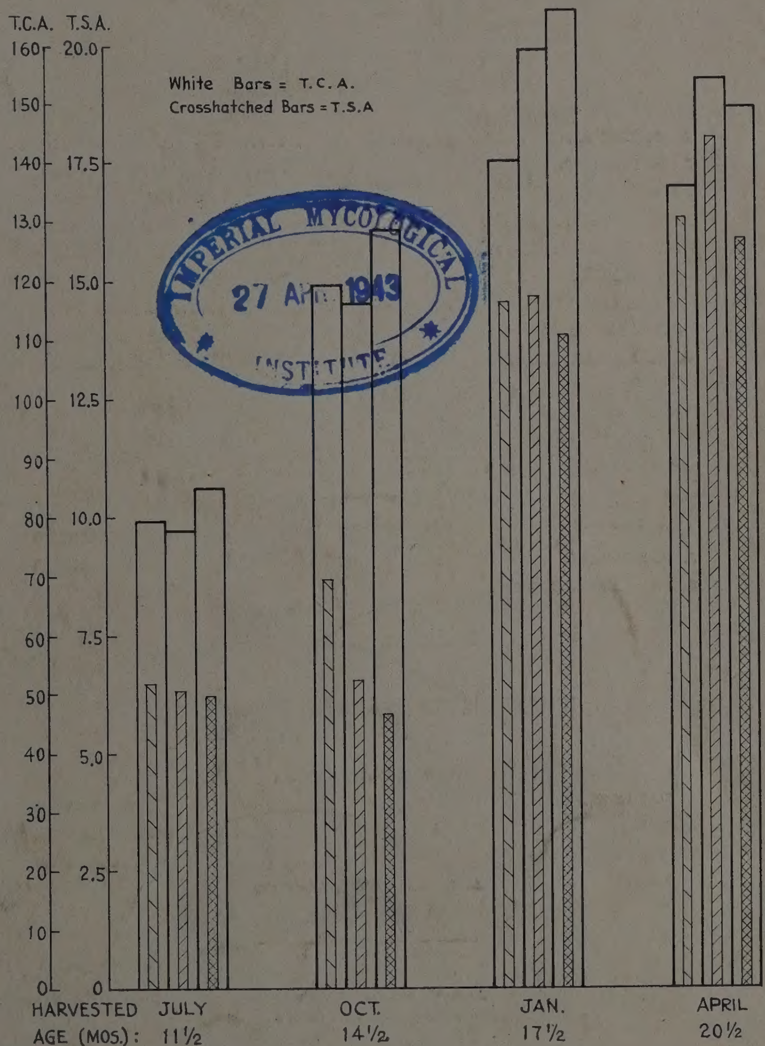
VOLUME XLVI NUMBER 4

THE HAWAIIAN PLANTERS' RECORD



In each of four harvests, the yields of 32-8560 cane and sugar are shown as obtained from applications of nitrogen at (left to right respectively) 100, 160, and 220 pounds per acre.

FOURTH QUARTER 1942

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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THE HAWAIIAN PLANTERS' RECORD

Vol. XLVI FOURTH QUARTER 1942 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

Nitrogen Studies

Comments by DR. A. L. DEAN

In this issue of the *Record* are two papers, each summarizing the results of large numbers of analytical determinations and each addressed to expanding our knowledge of the relations of nitrogen fertilization to cane growth and sugar yields. The results are not altogether in harmony, which may cause mental distress in some minds. It may be assumed that the laboratory work of chemical analyses has been competently done and that such apparent differences as exist arise from other causes.

It is, of course, true that one set of data was obtained from 31–1389 cane and the other from 32–8560. One hesitates, however, to place too much emphasis on that difference. Rather, one is inclined to look at the sampling methods for an explanation of such differences as the data present.

Sampling is one of the most difficult problems to solve in many types of chemical control. One cannot, for example, walk up to a 10,000-ton pile of coal, pick up a lump or two, analyze the sample and expect to get any reliable idea about the average composition of the pile. Sampling ore presents a similar problem and we are all familiar with the difficulty of getting a truly representative soil sample from an area of any substantial size.

Dr. Clements uses "five *selected* plants representing the average of the stand of those plants presumed still to be there at harvest" as material from which samples are prepared for analyses. Growth measurements were made on 20 "pilot plants in each plot" using the same plants throughout the cycle. From the crop harvest, the plants used for analytical purposes, and the growth measurements, the tonnages of cane per acre and the amounts of nitrogen per acre in the crop at various stages are computed. Dr. Clements explains that he uses the term plant to denote a single stalk with its green top and does not imply the whole stool.

Mr. Borden, on the other hand, cuts five feet of cane row and uses all the cane standing therein as the basis both for calculations and samples for analyses.

Results obtained by such different methods would scarcely be expected to be wholly consistent, but both may add to the sum total of our knowledge.

It is well to have clearly in mind the objectives of the two studies. Dr. Clements is satisfied that the cane plant itself is the best guide to follow in nitrogen fertilization. He is therefore concerned in finding a part of the plant the nitrogen content of which will be a reliable index of the nitrogen status of the whole plant and of the field. He presents evidence in the first part of his paper to show that he has found such index tissues. The next step is to correlate results from sample cane stalks with the progress of the field in order to develop a practical method for field control of nitrogen fertilization, and the second part of his paper is his contribution to that end.

The work of Mr. Borden and his collaborators is addressed to expanding our knowledge of the composition and behavior of the whole body of cane in a field throughout a crop with special reference to nitrogen relationships. Only indirectly does that work involve the use of the cane itself as a guide to fertilization. The methods followed indicate that a substantially larger quantity of nitrogen was present in the total cane blanket of the field than the amounts indicated by Dr. Clements to be in the crops he was studying. Borden's data also tend to emphasize the soil contribution of nitrogen and to suggest that soils more highly endowed with organic matter and nitrogen may make highly significant amounts of nitrogen available to growing cane.

One thing seems clear—we have some distance yet to go before arriving at a satisfactorily complete understanding of nitrogen-sugar cane relationships. I am again reminded of a comment once made to me by Russell H. Chittenden, the pioneer of biological chemistry in America. Said he, "A properly authenticated scientific fact is good for all time, what it means is subject to continuing revision in the light of new knowledge."

Nitrogen and Sugar Cane

The Nitrogen Index and Certain Quantitative Field Aspects*

By Harry F. Clements and S. Moriguchi

It has already been shown that yields and quality of sugar cane are correlated very closely with the amount of atmospheric energy available to a crop. Because of the variation in climate from season to season and from year to year, as well as in the abilities of a crop to take maximum advantage of the available energy, it is clearly apparent that the manipulation of moisture and fertilizer elements by the grower must be based upon the needs of the crop as reflected by it. In Part I of this paper evidence is presented showing that the nitrogen level of the elongating cane blades or of the green-leaf cane blades serves as a very reliable index to the nitrogen level of the plant itself. In Part II certain quantitative aspects are presented which show the crop absorption of nitrogen applied to the soil. Two cases are presented in which nitrogen was applied empirically and two cases in which it was applied according to the apparent needs of the plants in relation to the atmospheric energy available.

Introduction

Although it is recognized that no one essential factor in a plant's metabolism can be wholly isolated from the others, it is nonetheless desirable and necessary to view each factor before attempting to gain a concept of the whole as affected by its various parts—particularly those parts which under field conditions are subject to manipulation. Such factors as moisture and the soil elements, particularly nitrogen, phosphorus, potash and at times certain other elements when supplied in proper amounts, enable the plant to take maximum advantage of the atmospheric energy into which it projects itself. Before it is possible to provide the proper amounts of each of these to a crop, it is necessary to select an index tissue which can be used to follow the levels of each factor as the crop grows. Such a tissue must reflect in a high degree of correlation the levels within the whole plant†, for as the absorption and utilization of any factor varies, such variations should be reflected by the index tissue. It is the purpose of this paper to establish the tissue which can be used simply and easily to gain a measure of the nitrogen level within the sugar cane plant and secondly, to present certain data collected from field-grown crops which suggest the amounts of nitrogen contained by the growing crop. Simi-

* Published by permission of the Director of the Hawaii Agricultural Experiment Station as Technical paper No. 104.

† In this paper, the term ''plant'' is used to denote a single stalk with its green top and does not imply the whole stool.

lar reports will appear shortly dealing with potassium, phosphorus, calcium, and available carbohydrates.

Part I

Nitrogen Index

The concept of using leaves as index tissues for nitrogen, potash, and phosphorus as well as other elements apparently dates back to 1869 to the work of Isidore Pierre (9) who noted that there were changes in the composition of leaves associated with differences in environment. The development and application of "diagnostic foliare," however, is credited to two other Frenchmen, Henri Lagatu and Louis Maume, who began their researches on the grape in 1923. Since then they have published many papers developing and applying the principles of foliar diagnosis (6, 7, 8).

In 1937, Thomas (11) of the Pennsylvania Agricultural Experiment Station began a series of papers dealing with the principles and practices of foliar diagnosis as applied to fertilizer-requirement studies, using a variety of plants ranging from herbaceous crops such as potato (12) and corn (13) to arborescent plants such as apple (11). In addition to using the principle in establishing evaluation of the N-P-K unit, both in its quantitative and qualitative aspects, he has recently applied it to similar evaluation of the Ca-Mg-K unit (14). In all of these studies leaves of the same morphological age serve as the indicator of the various elements being measured.

Before it will be possible to evaluate these ideas as aids in the solution of problems met in the culture of sugar cane, it is necessary first to select the correct index tissue.

Experimental

The variety of sugar cane 31-1389 was planted and grown, as already described, at Kailua, a place of low light intensity and at Waipio, a place of high light intensity (1). Approximately each month growth measurements and collections of plants were taken. From each of the fourteen plots (both plant crop and first ratoon) five *selected* plants representing the average of the stand of those plants presumed still to be there at harvest were taken and divided into their several parts as already described (2). Green weights and dry weights were obtained and the material was ground in a Wiley mill and stored for analysis. The total nitrogen of each plant part was determined by use of the official Kjeldahl method without modification for nitrates, which do not normally appear in the above-ground parts of this plant.

The parts of the plant used in these studies are as follows: three-internode units of the leafless cane stem numbered acropetally, and the green top divided into the spindle cluster (leaves 1 and 2—counting the emerging spindle leaf as No. 1 and all the included embryonic leaves down to within 5 inches of the stem

tip), elongating cane blades (leaf blades of leaves 3, 4, 5, and 6), elongating cane sheaths (sheaths of leaves 3, 4, 5, and 6), green-leaf cane blades (all living leaves below No. 6), green-leaf cane sheaths (sheaths of leaves below No. 6), meristematic material (including the meristem of the stem severed below the node to which leaf No. 2 is attached and including five inches of meristematic leaf bases), elongating cane (the elongating portion of the stem between the nodes carrying leaves Nos. 2 and 6), the green-leaf cane (that portion of the cane between node of leaf No. 6 and that carrying the oldest living leaf, inclusive).

In some of the tables of data which follow, the nitrogen content of the whole plant, green top, and meristematic material and elongating cane is reported. These values are calculated, weighted values obtained from the analysis and weights of the several parts.

Data

As in previous papers of this series, it is not necessary to present the data of every plot used, even though all such data are statistically treated later on. The nitrogen values for the various plant parts have already been reported for Plots A at Kailua and Waipio (1). It is useful for this paper to present similar tables for Plots C at Kailua and Waipio as well as for the ratoon crops of Plots RA at Kailua and Waipio, and Plot RB at Waipio.

Casual inspection of the data from Plot C at Kailua (Table I) reveals a high nitrogen level throughout the plant as compared with Plot C at Waipio (Table II). Similar inspection of Plot RA at Kailua (Table III) shows a markedly lower general level than in Plot C for Kailua and more nearly comparable to the data for Plot C at Waipio. Plots RA and RB at Waipio (Tables IV and V) are the lowest of all. (Although the actual culture and yields are of no concern in this paper it may be stated that Waipio Plot C received 216 pounds of nitrogen and yielded 13 tons of sugar, Kailua Plot C received 160 pounds of nitrogen and yielded 7.1 tons of sugar, Kailua Plot RA received 100 pounds of nitrogen and yielded 6.0 tons of sugar, while Waipio Plot RA received 170 pounds of nitrogen and yielded 15.1 tons of sugar, and Waipio Plot RB received 180 pounds nitrogen and yielded 16.3 tons of sugar.) Here, we are concerned only with the analysis of a volume of data including plants very high in nitrogen as well as plants, though highly productive, which are very low in their nitrogen composition. It should be possible from such data to obtain a useful and accurate index tissue, one which will reliably indicate the nitrogen levels of plants grown at different light intensities, as well as those grown at different levels of soil nitrogen.

Before proceeding with the selection of the nitrogen index tissue, it is necessary further to inspect Tables I to V. It is quite apparent that each tissue has a rather characteristic amount of nitrogen. The meristematic material, as may be expected, has the highest level, followed by the elongating cane. In other words, in the region of the plant where growth occurs, the nitrogen content based on dry matter is highest. The green, leafy tissues of the plant, the spindle cluster and the two blade samples are next in order, and although they are of the same general range,

TABLE I

TOTAL NITROGEN—% DRY MATTER

KAILUA PLOT C

Part	1939									1940								
	Apr. 21	May 26	Jun. 27	Jul. 23	Sep. 2	Sep. 30	Oct. 28	Nov. 24	Dec. 27	Feb. 2	Mar. 9	Apr. 13	May 18	Jun. 21	Jul. 27	Aug. 31	Oct. 5	Nov. 9
Meristem	3.30	2.47	2.95	2.33	2.27	3.47	2.86	3.03	3.62	3.30	2.94	3.28	3.36	2.78	1.48	3.46	2.62	3.28
Spindle cluster	1.62	1.22	1.03	1.00	.86	1.16	1.12	1.16	1.08	1.10	1.06	1.00	1.02	.92	.75	1.06	1.06	1.00
Elongating cane blades	1.80	1.37	1.17	1.22	1.07	1.21	1.24	1.37	1.26	1.16	1.27	1.13	1.09	.98	.92	1.11	1.17	1.19
Green-leaf cane blades	1.75	1.28	1.07	1.10	.91	1.05	.98	1.04	1.01	1.07	1.01	1.11	1.01	.85	.82	.97	.89	1.07
Elongating cane sheaths	.64	.44	.39	.42	.38	.49	.50	.51	.54	.51	.44	.46	.47	.39	.34	.47	.48	.45
Green-leaf cane sheaths	.57	.43	.34	.36	.33	.32	.33	.38	.38	.41	.36	.36	.36	.32	.32	.32	.33	.23
Elongating cane	2.92	1.40	1.36	.99	1.01	1.55	1.35	1.41	1.38	1.69	1.38	1.46	1.74	1.11	1.01	1.64	1.38	1.50
Green-leaf cane	1.33	.73	.42	.52	.41	.47	.53	.52	.45	.56	.58	.56	.56	.32	.33	.40	.38	.31
Top internodes			.41	.52	.46	.41	.44	.63	.49	.46	.47	.45	.45	.32	.34	.34	.27	.31
16th 3 internodes																	.29	.30
15th 3 internodes																	.29	.30
14th 3 internodes																.31	.29	.30
13th 3 internodes																.42	.31	.26
12th 3 internodes															.37	.34	.30	.26
11th 3 internodes														.42	.40	.31	.24	.25
10th 3 internodes													.47	.42	.41	.32	.23	.23
9th 3 internodes													.36	.39	.39	.29	.18	.21
8th 3 internodes												.35	.39	.34	.33	.25	.16	.16
7th 3 internodes										.42	.40	.38	.39	.31	.28	.20	.14	.15
6th 3 internodes										.40	.42	.34	.37	.33	.25	.20	.12	.15
5th 3 internodes									.49	.43	.47	.37	.38	.33	.24	.19	.11	.15
4th 3 internodes								.54	.47	.45	.44	.40	.36	.31	.22	.18	.10	.17
3rd 3 internodes					.51		.46	.57	.45	.37	.39	.38	.37	.30	.22	.16	.09	.15
2nd 3 internodes				.67	.64	.46	.47	.68	.43	.33	.36	.37	.37	.28	.22	.13	.09	.13
1st 3 internodes			.51	.82	.99	.52	.62	.86	.48	.41	.40	.41	.42	.30	.23	.12	.13	.13

TABLE II

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT C

Part	1939									1940								
	Apr. 20	May 25	Jun. 26	Jul. 22	Sep. 1	Sep. 29	Oct. 27	Nov. 25	Dec. 26	Feb. 1	Mar. 8	Apr. 12	May 17	Jun. 20	Jul. 26	Aug. 30	Oct. 4	Nov. 8
Meristem	3.11	3.29	3.53	3.36	2.79	3.38	2.82	3.03	3.30	2.82	3.36	2.75	3.60	2.54	2.66	3.44	2.84	2.48
Spindle cluster	1.45	1.03	1.15	1.11	1.08	1.13	1.13	1.19	1.02	.98	1.00	.85	1.07	.87	.89	.88	.86	.75
Elongating cane blades	1.57	1.02	1.16	1.21	1.12	1.13	1.19	1.25	1.20	1.05	.97	.88	.90	.91	.86	.91	.93	.83
Green-leaf cane blades		.99	.95	.93	.86	.89	.96	.87	.96	.98	.85	.73	.78	.71	.68	.66	.69	.68
Elongating cane sheaths	.48	.39	.47	.46	.42	.45	.49	.47	.46	.43	.38	.35	.38	.41	.38	.38	.35	.29
Green-leaf cane sheaths		.29	.31	.32	.31	.34	.37	.33	.29	.35	.29	.27	.30	.30	.27	.25	.27	.25
Elongating cane	1.13	2.04	1.26	1.43	1.06	1.48	1.44	1.18	2.03	1.74	1.54	1.52	1.63	1.72	1.42	1.55	1.38	1.41
Green-leaf cane		.56	.38	.33	.34	.37	.38	.39	.41	.52	.43	.38	.48	.43	.43	.38	.28	.32
Top internodes				.22	.25	.30	.29	.29	.23	.47	.29	.32	.37	.33	.38	.19	.20	.20
17th 3 internodes																	.23	.18
16th 3 internodes																	.24	.19
15th 3 internodes																	.23	.17
14th 3 internodes																.17	.20	.14
13th 3 internodes															.28	.19	.20	.13
12th 3 internodes													.26	.33	.26	.18	.18	.12
11th 3 internodes													.30	.28	.23	.18	.18	.14
10th 3 internodes													.32	.24	.21	.17	.17	.13
9th 3 internodes												.26	.31	.18	.18	.15	.15	.11
8th 3 internodes											.25	.23	.27	.17	.12	.11	.11	.10
7th 3 internodes										.30	.19	.19	.27	.15	.13	.09	.09	.10
6th 3 internodes									.19	.27	.16	.17	.22	.15	.11	.09	.09	.08
5th 3 internodes								.26	.20	.24	.16	.15	.24	.13	.12	.08	.09	.08
4th 3 internodes						.24	.26	.22	.20	.27	.16	.16	.19	.14	.11	.10	.09	.08
3rd 3 internodes					.25	.25	.24	.22	.19	.23	.16	.15	.21	.12	.09	.08	.09	.08
2nd 3 internodes					.23	.24	.24	.20	.18	.26	.15	.16	.22	.13	.07	.09	.09	.08
1st 3 internodes			.33	.27	.30	.30	.27	.23	.21	.26	.17	.19	.27	.15	.11	.08	.08	.10

TABLE III

TOTAL NITROGEN—% DRY MATTER

KAILUA PLOT RA

Part	1940					1941										1942			
	Jul. 27	Aug. 31	Oct. 5	Nov. 9	Dec. 14	Jan. 18	Feb. 22	Mar. 29	May 3	Jun. 7	Jul. 12	Aug. 16	Sep. 20	Oct. 24	Nov. 29	Jan. 3	Feb. 7	Mar. 14	Apr. 18
Meristem	3.10	4.14	4.00	4.14	3.48	3.38	2.76	2.56	2.24	2.18	2.61	3.11	1.92	2.42	2.30	2.46	2.58	1.58	2.26
Spindle cluster	1.17	1.29	1.32	1.22	1.12	1.08	.94	.92	.86	.81	.87	.88	.82	.95	.91	.89	.96	.84	.94
Elongating cane blades	1.51	1.36	1.34	1.30	1.31	1.27	1.13	1.04	.98	.80	.85	.89	.99	.96	1.08	.95	1.00	.88	.92
Green-leaf cane blades	1.59	1.28	1.22	1.11	1.13	1.13	.98	.92	.80	.71	.69	.72	.71	.83	.86	.80	.81	.79	.76
Elongating cane sheaths	.60	.58	.59	.54	.51	.48	.41	.34	.33	.32	.34	.34	.35	.37	.39	.38	.34	.34	.40
Green-leaf cane sheaths	.59	.42	.48	.41	.42	.41	.38	.38	.30	.31	.26	.26	.26	.28	.29	.30	.34	.29	.32
Elongating cane	2.20	1.60	1.80	1.90	1.38	1.54	1.48	1.22	1.16	1.04	1.18	1.30	.96	1.24	1.02	1.14	1.22	1.16	1.32
Green-leaf cane	1.87	.67	.47	.41	.45	.44	.56	.49	.53	.46	.24	.37	.29	.26	.26	.34	.54	.59	.70
Top internodes			.33	.19	.36	.28	.42	.45	.43	.34	.35	.28	.24	.20	.19	.22	.28	.32	.64
16th 3 internodes																			.50
15th 3 internodes																		.11	.34
14th 3 internodes																	.20	.17	.26
13th 3 internodes																.18	.17	.15	.19
12th 3 internodes															.19	.22	.17	.16	.17
11th 3 internodes													.23	.19	.18	.23	.24	.16	.16
10th 3 internodes												.27	.22	.19	.18	.24	.16	.16	.16
9th 3 internodes											.47	.27	.22	.20	.21	.21	.17	.17	.18
8th 3 internodes										.48	.37	.27	.21	.19	.18	.23	.17	.18	.18
7th 3 internodes									.44	.43	.32	.24	.21	.18	.18	.20	.16	.17	.23
6th 3 internodes							.36	.36	.33	.33	.24	.18	.16	.13	.14	.15	.14	.15	.18
5th 3 internodes							.26	.28	.23	.27	.17	.14	.11	.12	.11	.12	.12	.12	.15
4th 3 internodes					.37	.26	.23	.21	.18	.20	.13	.13	.10	.10	.09	.11	.10	.10	.12
3rd 3 internodes					.32	.22	.22	.18	.16	.18	.11	.08	.09	.09	.09	.09	.09	.11	.11
2nd 3 internodes				.35	.30	.22	.21	.19	.15	.18	.12	.10	.09	.10	.10	.09	.10	.12	.13
1st 3 internodes		.83	.43	.41	.36	.21	.29	.25	.19	.22	.17	.16	.10	.11	.11	.12	.14	.16	.17

TABLE IV

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT RA

Part	1940					1941										1942			
	Jul. 26	Aug. 30	Oct. 4	Nov. 8	Dec. 13	Jan. 17	Feb. 21	Mar. 28	May 2	Jun. 6	Jul. 12	Aug. 17	Sep. 19	Oct. 24	Nov. 28	Jan. 2	Feb. 6	Mar. 13	Apr. 17
Meristem	3.80	3.60	3.44	3.62	3.46	3.40	2.86	2.58	4.22	3.44	3.34	3.48	3.64	3.14	3.10	3.24	3.06	2.76	2.66
Spindle cluster	1.26	1.01	1.04	1.12	1.06	.99	.89	.86	1.31	.98	1.02	.97	.94	1.01	.97	.92	.85	.90	.89
Elongating cane blades	1.30	1.00	1.03	1.11	1.14	1.06	.95	.87	1.14	1.03	.96	.96	.99	1.00	1.13	.99	.86	.84	.81
Green leaf cane blades	1.34	.87	.80	.82	.85	.81	.78	.61	.77	.80	.69	.73	.69	.74	.81	.75	.68	.66	.55
Elongating cane sheaths	.57	.44	.43	.44	.40	.42	.39	.30	.51	.42	.38	.43	.40	.38	.44	.38	.48	.35	.34
Green-leaf cane sheaths	.47	.29	.29	.30	.29	.32	.27	.24	.28	.27	.26	.25	.28	.33	.32	.33	.28	.29	.26
Elongating cane	2.16	1.40	1.32	1.30	1.34	1.58	1.28	1.30	2.14	1.56	1.36	1.44	1.58	1.30	1.52	1.28	2.00	1.40	1.44
Green-leaf cane	1.02	.32	.20	.30	.25	.30	.30	.35	.71	.39	.38	.25	.28	.35	.35	.29	.41	.33	.47
Top internodes			.11	.16	.14	.17	.19	.25	.29	.35	.29	.22	.23	.33	.34	.26	.27	.19	.29
18th 3 internodes																		.15	.20
17th 3 internodes																.25	.20	.14	.14
16th 3 internodes																.20	.16	.13	.13
15th 3 internodes														.28		.18	.15	.12	.11
14th 3 internodes														.18	.21	.19	.11	.12	.11
13th 3 internodes													.24	.18	.16	.17	.09	.12	.11
12th 3 internodes													.22	.18	.16	.15	.10	.10	.11
11th 3 internodes												.19	.20	.14	.13	.15	.11	.11	.14
10th 3 internodes											.29	.17	.21	.14	.13	.16	.11	.11	.14
9th 3 internodes											.27	.17	.18	.13	.12	.18	.12	.13	.14
8th 3 internodes										.32	.23	.13	.14	.11	.13	.15	.12	.11	.14
7th 3 internodes								.19	.23	.24	.17	.12	.11	.12	.13	.12	.11	.11	.12
6th 3 internodes							.16	.14	.16	.18	.15	.09	.10	.09	.09	.09	.10	.10	.11
5th 3 internodes						.14	.18	.13	.14	.15	.11	.09	.13	.10	.08	.09	.09	.09	.11
4th 3 internodes					.11	.14	.09	.11	.11	.12	.10	.08	.08	.07	.08	.09	.09	.09	.09
3rd 3 internodes				.12	.10	.10	.10	.09	.10	.11	.11	.07	.07	.08	.07	.08	.08	.07	.10
2nd 3 internodes				.09	.08	.10	.09	.10	.10	.11	.10	.08	.08	.07	.07	.09	.08	.08	.09
1st 3 internodes		.20	.10	.11	.10	.12	.13	.14	.13	.14	.11	.10	.08	.12	.09	.08	.10	.09	.10

TABLE V

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT RB

Part	1940			1941										1942					
	Oct. 4	Nov. 8	Dec. 13	Jan. 17	Feb. 21	Mar. 28	May 2	Jun. 6	Jul. 11	Aug. 16	Sep. 19	Oct. 24	Nov. 28	Jan. 2	Feb. 6	Mar. 13	Apr. 17	May 22	Jun. 26
Meristem	5.04	4.00	3.76	3.74	3.08	2.98	2.86	2.57	3.02	3.94	3.48	3.24	3.66	2.58	3.26	3.00	2.68	2.44	1.76
Spindle cluster	2.02	1.24	1.09	1.09	.97	.87	.83	.75	.84	1.16	1.02	1.01	1.00	.96	1.03	.96	.91	.83	.80
Elongating cane blades	1.94	1.19	1.06	1.10	.98	.90	.88	.80	.77	1.11	1.05	1.10	1.13	1.02	.96	.90	.85	.78	.72
Green-leaf cane blades	1.87	1.33	.93	.95	.82	.71	.62	.55	.59	.77	.80	.85	.83	.77	.79	.68	.70	.59	.52
Elongating cane sheaths	.94	.60	.49	.47	.42	.34	.32	.28	.33	.56	.48	.40	.49	.40	.36	.40	.36	.32	.27
Green-leaf cane sheaths	.72	.39	.44	.34	.31	.28	.22	.21	.21	.28	.31	.32	.27	.29	.27	.30	.27	.25	.24
Elongating cane	3.98	1.66	1.66	1.71	1.40	1.24	1.12	.96	1.06	2.06	1.62	1.74	1.70	1.46	1.54	1.54	1.30	1.18	1.14
Green leaf cane	2.12	.51	.30	.30	.28	.24	.22	.25	.23	.41	.38	.40	.37	.39	.30	.41	.34	.36	.38
Top internodes				.16	.15	.16	.14	.13	.13	.32	.33	.28	.30	.31	.21	.21	.21	.28	.34
16th 3 internodes																		.23	.25
15th 3 internodes																	.18	.18	.16
14th 3 internodes															.22	.23	.15	.16	.13
13th 3 internodes															.18	.20	.14	.13	.13
12th 3 internodes														.28	.15	.21	.13	.12	.13
11th 3 internodes														.20	.13	.14	.13	.11	.12
10th 3 internodes												.22	.20	.17	.13	.14	.12	.12	.12
9th 3 internodes											.25	.20	.16	.13	.11	.12	.12	.11	.11
8th 3 internodes											.21	.16	.13	.12	.11	.12	.11	.12	.11
7th 3 internodes									.11	.20	.15	.11	.10	.12	.10	.11	.11	.11	.10
6th 3 internodes									.11	.16	.11	.11	.09	.11	.09	.10	.10	.10	.10
5th 3 internodes								.12	.10	.13	.10	.11	.10	.10	.09	.09	.09	.09	.09
4th 3 internodes						.15	.13	.10	.09	.11	.10	.10	.09	.09	.09	.09	.08	.10	.09
3rd 3 internodes						.12	.10	.10	.09	.10	.09	.08	.08	.09	.09	.09	.08	.10	.08
2nd 3 internodes				.15	.13	.12	.10	.09	.09	.10	.09	.08	.08	.09	.09	.10	.09	.09	.09
1st 3 internodes			.20	.15	.14	.22	.12	.13	.15	.14	.10	.11	.10	.13	.10	.12	.10	.13	.11

the elongating cane blades are highest, the spindle cluster next, and finally the green-leaf cane blades. The range within each of these may be fairly considerable depending upon such factors as soil supply of nitrogen and moisture, and growth rate. The nitrogen level of the leaf sheaths also fluctuates with the levels in the blades but the nitrogen level is much lower and hence the range of variation within the sheath tissue is very narrow throughout the crop cycle. Thus, while the nitrogen level of the elongating cane blades of Plot C Kailua varies from 0.92 per cent to 1.80 per cent, the corresponding sheaths vary from 0.34 to 0.64 per cent. Although the percentage variation is about the same, the actual variation is much greater in the former.

The nitrogen content of the green-leaf cane, as might be anticipated, is between that of the elongating and the mature cane. The nitrogen content of the various internodes of the mature cane is in general highest at the top and lowest toward the base. Further, where the application of nitrogen is excessive (Tables I, II, III), the nitrogen content of the cane is high in the early months of the crops with a progressive diminution toward harvest. When the application of nitrogen is more in keeping with the requirements of the crop, the nitrogen content of the cane during the early months is much the same as later on (Tables IV and V). The larger quantities in the over-fertilized cane have the aspect of a reserve but in reality are an attribute of the maturation of cane tissues. In those plants growing under conditions of abundant moisture and nitrogen, the maturation of stem tissues does not proceed to the same degree of completion and as early as in plants grown under regulated nitrogen and moisture conditions. The likelihood of physical damage to such immature cane is very great.

In choosing among possible tissues to serve as an index to the nitrogen levels in the plant, several factors must be borne in mind: (1) It must be possible to select tissues of the same approximate morphological age; (2) the tissue selected should be easily accessible; (3) it must be possible to separate the chosen tissue from the plant with considerable precision; (4) the range of nitrogen in the chosen tissue should be as large as possible so that errors inherent in the chemical procedure are minimized; (5) the degree of correlation between the nitrogen content of the index tissue and the active portion of the plant itself should be very high; and (6) the index tissue should be as homogeneous as possible to simplify mixing and preparation of samples for analysis.

On *a priori* considerations alone, the blades of certain leaves suggest themselves as the desirable tissue. The sheaths of these leaves are not desirable because of the small range in nitrogen levels. The meristematic material, the elongating cane, the green-leaf cane are separated from the plant on arbitrary bases and cannot be collected with continuing and uniform precision. The same is true of the spindle cluster. Furthermore, preliminary statistical examination of the relation between the nitrogen levels of these tissues and the green top, the whole plant, and the growing tissues of the stem tip shows that the elongating cane blades and the green-leaf cane blades are much superior to any of the other possible tissues. In addition these can be numbered from the youngest emerging leaf downward and hence collections can be made simply and with considerable precision. Although the elongating cane blades and the green-leaf cane blades satisfy the requirements of index tissues, two points of difference occur. The elongating cane blades are

always of the same order. Thus, leaves 3, 4, 5 and 6 are always present on a plant. In this respect, leaves of the same morphological age are always available. However to obtain these leaves together with their associated sheaths requires the decapitation of the plant. This is an objection, although not a serious one, since in the first place if each acre of cane were sampled only some 90 out of a total of some 27,000 plants per acre would so be sacrificed in an entire crop cycle, and in the second place, many of the decapitated plants develop a side shoot (lala) and continue to grow. On the other hand the green-leaf cane blades vary in number from collection to collection. Thus, when the plant is growing vigorously there are more leaves in this sample than toward harvest, when there may be no living leaves at all below No. 6. Further, a larger range in nitrogen is thus introduced, since in the vigorous plants there are many relatively young (physiologically) leaves characterized by a relatively high nitrogen level while in samples nearing maturity, these leaves are relatively old with a low nitrogen level. Because of this shifting in leaf activity and number, the green-leaf cane blades yield somewhat better correlations with the nitrogen of the plant itself. Whether or not such artificial improvement of the correlation is desirable cannot be stated at this time.

To obtain a complete analysis of the reliability of these two tissues, the methods of statistical linear regression were applied to each of the eight plant-crop plots (four at Waipio and four at Kailua) and to each of the six ratoon crops (three at Waipio and three at Kailua). The fourth ratoon plot was not far enough advanced to be included. In each case the regression equation expressing the relation between each of the blade samples and the nitrogen level of the entire plant, the green top only (including the leaves, sheaths, green-leaf cane, elongating cane and the meristematic material), and the growing tissues (the elongating cane, meristem and meristematic leaf basis) was determined. In Table VI are recorded the t values showing the significance which can be attached to the regressions. Since there was some small variation in the number of pairs of variables among individual plots, the t values in the columns should be compared vertically with that in mind. However, they can be compared horizontally and can be used as a measure of relative reliability. The higher the value for t, the more significant is the regression between the green top and the given tissue.

TABLE VI

t VALUES—GREEN TOP VS. LEAF SAMPLES

(All values highly significant)

Plot	Number of variables	t values: Elongating cane blades	t values: Green-leaf cane blades
Kailua:			
Plot A*	15	3.44	3.24
Plot B	16	6.66	8.48
Plot C	17	3.58	5.62
Plot D	18	5.43	10.49
Plot RA	19	7.15	10.39
Plot RB	18	17.04	13.29
Plot RC	14	8.30	11.98
All Kailua Plots	117	20.90	26.05

Waipio:			
Plot A	15	4.54	3.29
Plot B	17	5.40	8.19
Plot C	18	5.74	13.09
Plot D	18	4.64	9.83
Plot RA	19	4.70	7.26
Plot RB	18	14.25	13.50
Plot RC	15	7.85	13.02
All Waipio Plots.....	120	18.14	28.05
All Plots	237	28.67	38.93

* Plots A, B, C, D are plant crops. Plots RA, RB, RC are ratoon crops which followed the corresponding plant crops.

Three observations may be made on the data in Table VI: (1) The *t* values for both leaf samples are of such high order that either tissue could be used to predict the nitrogen level in the green top of the plant; (2) in general the green-leaf cane blades yield higher *t* values; and (3) in general the ratoon crops yield higher significance than the plant crop. This fact is explainable on two bases, one subjective, the other objective. As the work proceeded with the plant crops, subconscious improvements and standardization of techniques of collecting and preparing samples and their subsequent analysis undoubtedly occurred. Further, the plant crops were handled in the field according to established methods, empirically applied, while the ratoon crop was handled according to the requirements of the

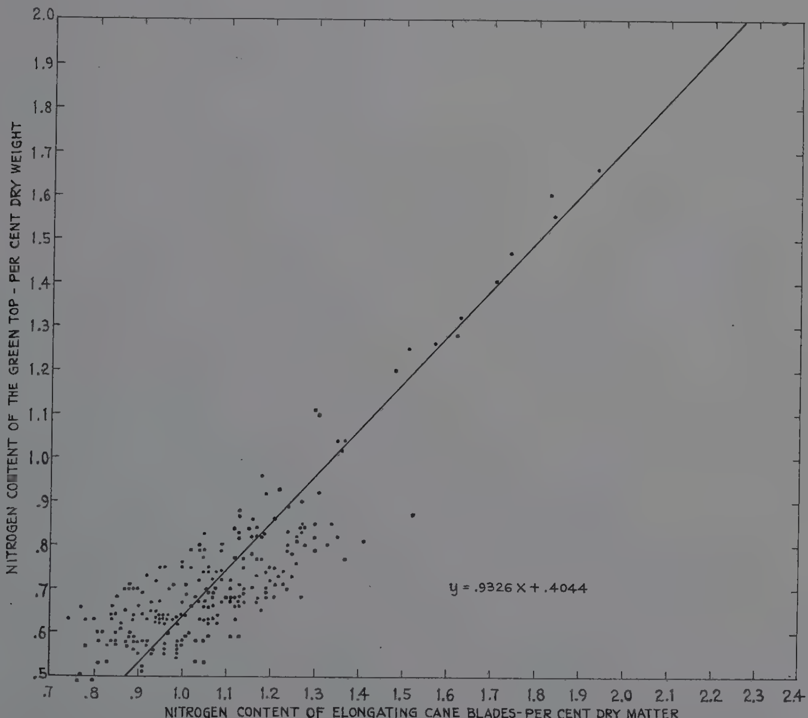

Fig. 1. Linear regression between the total nitrogen contents of the green top and elongating cane blades. Combined data of all plots.

plants. The difference in the handling of the two crops consisted of smaller fertilizer application and also fewer irrigations in the ratoon crop cycle.

The regression equation for each of the fourteen plots has been calculated, but it seems necessary to present only the equation for the combined plots. The linear regression equations for expressing the relationship between the green top and the elongating cane blades and green-leaf cane blades, are $.9326X + .4044$ and $1.1172X + .0860$, respectively. For purposes of demonstration, the data showing the relationship between the green top and the elongating cane blades are plotted in Fig. 1, revealing the high order of correlation between the two. However, were one interested in predicting the nitrogen content of the green top from the index tissue, it is apparent that a better fitting of curves could be had. The same generalization holds for the relation between the nitrogen content of the green top and that of the green-leaf cane blades. Application of the second degree polynomial resulted in the equation $y = .5354 + .01666X + .00569X^2$ for the elongating cane blades and $y = .5213 + .02349X + .00397X^2$ for the green-leaf cane blades. The latter is plotted in Fig. 2.

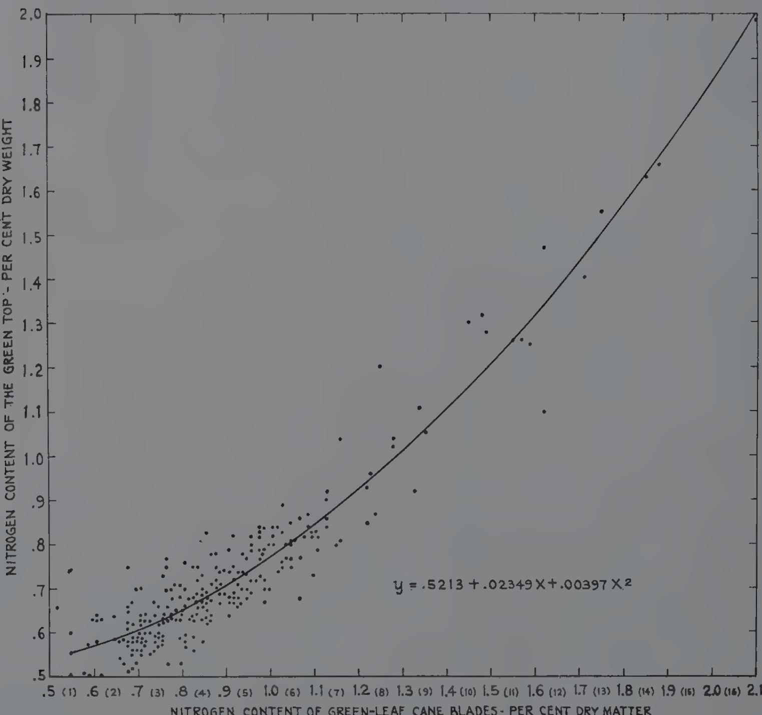

Fig. 2. Curvi-linear regression between the total nitrogen contents of the green top and the green-leaf cane blades. Combined data of all plots. (Numbers in parenthesis are code numbers used in obtaining the equation.)

WHOLE PLANT VS. BLADE SAMPLES

The nitrogen levels of the entire plant were compared with those of the elongating cane blades and the green-leaf cane blades. The t values of the regression coefficients are reported in Table VII.

TABLE VII

t VALUES—WHOLE PLANT VS. BLADE SAMPLES

(All values highly significant except two.
* indicates significance between 5 and 1 per cent
† indicates no significance)

Plot	t values: Elongating cane blades	t values: Green-leaf cane blades
Kailua:		
Plot A	2.67*	1.80†
Plot B	6.16	7.05
Plot C	3.13	3.70
Plot D	4.77	7.06
Plot RA	7.64	11.36
Plot RB	11.05	15.04
Plot RC	6.00	8.96
All Kailua Plots	18.17	22.61
Waipio:		
Plot A	6.01	4.89
Plot B	6.22	11.08
Plot C	5.90	10.11
Plot D	6.20	9.01
Plot RA	3.54	9.35
Plot RB	9.23	13.94
Plot RC	5.29	9.74
All Waipio Plots	15.89	26.66
All Plots	25.02	35.67

The regression equations showing the relation between the nitrogen level of the whole plant (all plots) and the elongating cane blades and the green-leaf cane blades are $.6031X + .8091$ and $.7376X + .5638$, respectively. In Figs. 3 and 4 the data are plotted about the regression line plotted from these equations. Although the general correlations as portrayed are highly significant, the spread of the points is much greater than in Figs. 1 and 2 where only the green top was involved. Clearly the lengthening cane imposes a unidirectional drag on the relationship, and where correlations are to be made with growth the green top will be of greater usefulness.

MERISTEMATIC MATERIAL AND THE ELONGATING CANE

One further relationship should be determined before establishing the nitrogen index. Since the nitrogen level of the growing tissue, the meristematic material and the elongating cane, will have a bearing on the amount of growth made as well as the quality of growth, a good correlation should exist between that nitrogen level and that of the index. In Table VIII the t values for this regression are given.

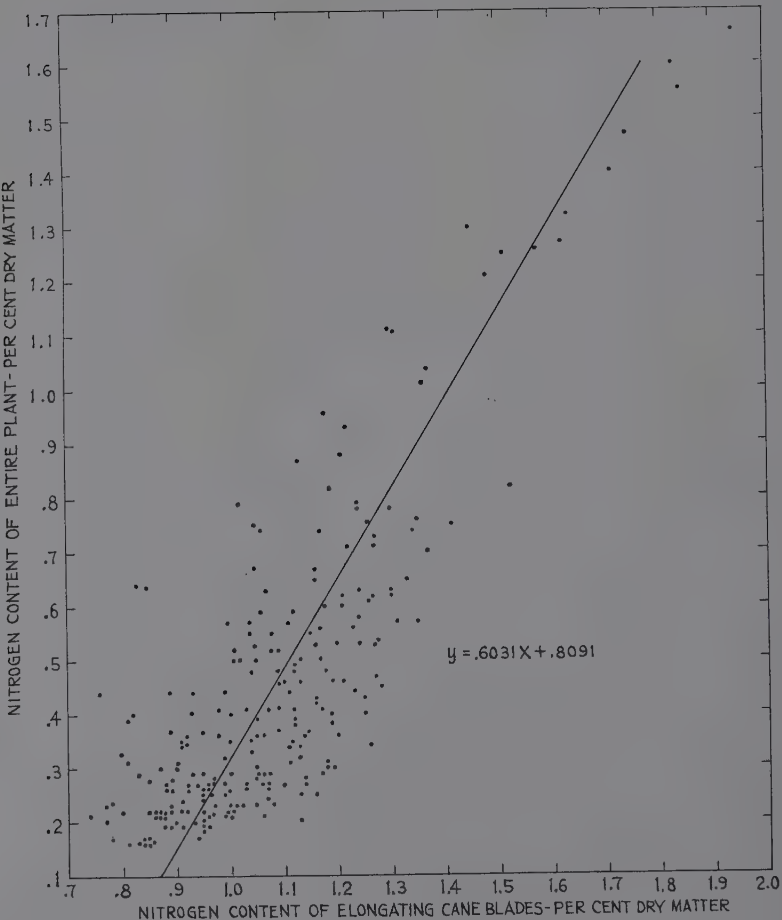

Fig. 3. Linear regression between the total nitrogen contents of the entire plant and the elongating cane blades. Combined data of all plots.

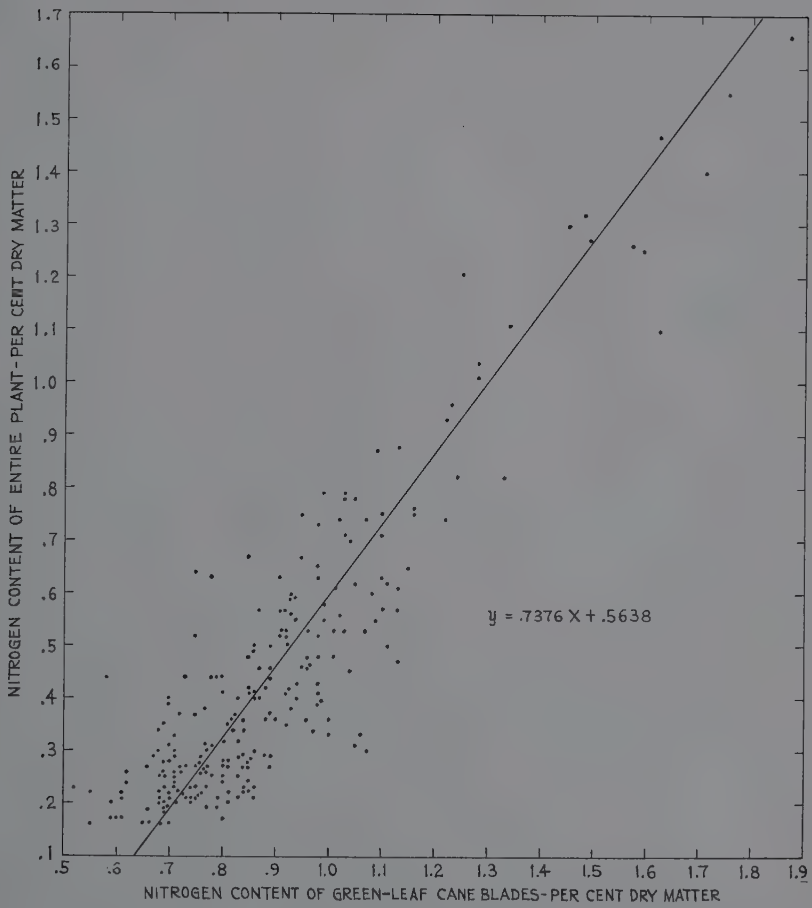

Fig. 4. Linear regression between the total nitrogen contents of the entire plant and the green-leaf cane blades. Combined data of all plots.

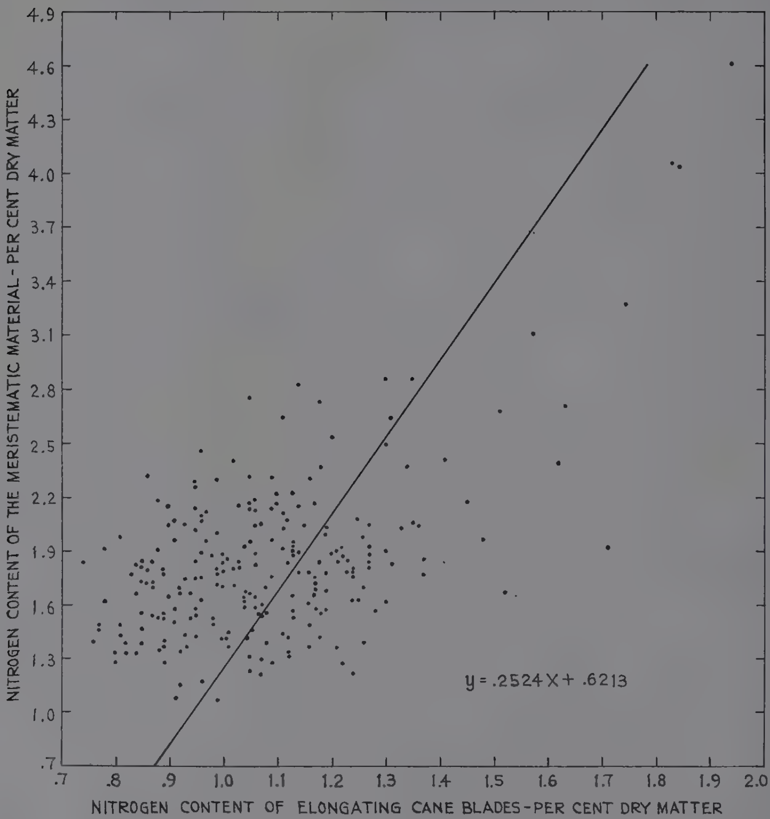

Fig. 5. Linear regression between the total nitrogen of the meristematic materials and the elongating cane blades. Combined data of all plots.

TABLE VIII

t VALUES—MERISTEMATIC TISSUES AND ELONGATING CANE VS. BLADE SAMPLES

(‡ indicates significance above 1 per cent; * between 5 and 1 per cent; no asterisk indicates lack of significance)

Plot	*t* values: Elongating cane blades	*t* values: Green-leaf cane blades
Kailua:		
Plot A	.39	.49
Plot B	5.00‡	6.11‡
Plot C	1.56	1.71
Plot D	1.79	1.35
Plot RA	6.26‡	6.88‡
Plot RB	11.41‡	12.13‡
Plot RC	5.93‡	8.54‡
All Kailua Plots	11.91‡	13.55‡

Waipio:		
Plot A	.96	.14
Plot B	3.41‡	5.24‡
Plot C	1.64	3.53‡
Plot D	.94	1.27
Plot RA	2.45*	2.49*
Plot RB	14.60‡	7.71‡
Plot RC	7.29‡	8.89‡
All Waipio Plots	6.72‡	10.29‡
All Plots	10.96‡	12.92‡

Figs. 5 and 6 show the nature of the correlation between the two leaf-blade samples and the growing tissues, but it is clear that the spread of the points is too great to allow for accurate prediction even though a curve were to be fitted to the data. A study of the *t* values in Table VIII shows that the levels of significance are consistently higher for the ratoon crops than for the plant crops. Although these data will not permit a clear dissection of the causes of the rather

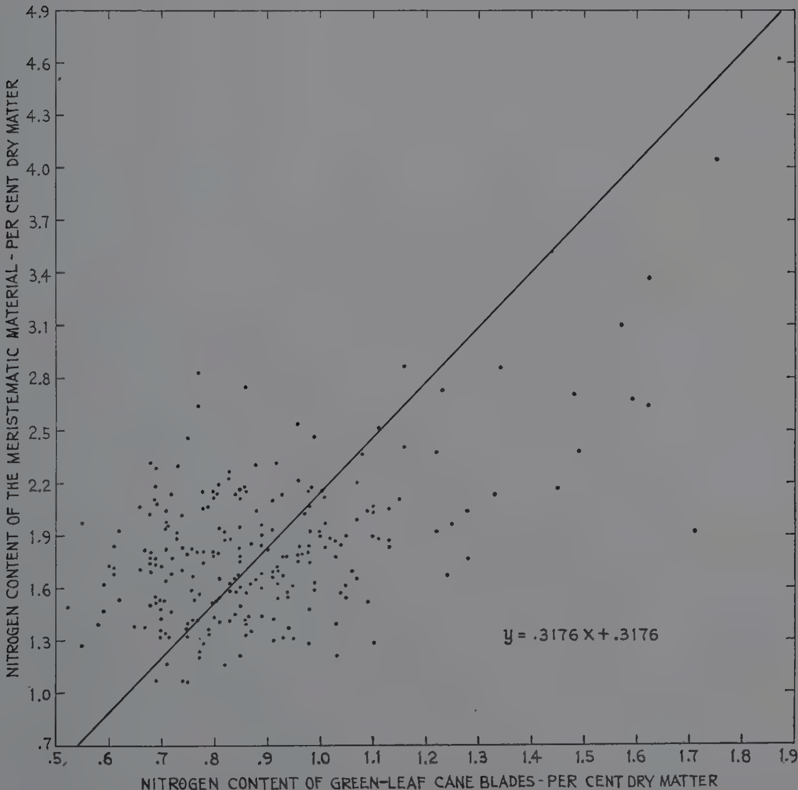

Fig. 6. Linear regression between the total nitrogen of the meristematic materials and the green-leaf cane blades. Combined data of all plots.

unsatisfactory relations between the nitrogen level of the growing point and the index tissues, it is pertinent, nevertheless, to indicate some of the possible causes.

(1) As already pointed out, the selection of the elongating cane samples and the meristematic material is arbitrary. Thus the meristematic material is the tip of stem from below the attachment of leaf No. 2 and includes about 5 inches of the meristematic and elongating leaf bases. The elongating cane is the portion of the stem between the attachment of leaf No. 6 and that of leaf No. 2. These separations were arbitrarily chosen because they did include the indicated tissues and also because in that way enough material was obtained for the necessary analyses. As time went on the collection of these samples, even though arbitrary, became more standardized and therefore there was an improvement in the correlations.

(2) The ratoon crops were fertilized with nitrogen as the plants appeared to require it. Less nitrogen was used in all cases than in the plant crops. It may follow from this that plants which are receiving nitrogen in relation to their needs will distribute it more precisely than those which have excessive amounts available.

(3) Hoagland *et al* (4, 5) and Steward *et al* (10) have shown that the accumulation of salts by a cell is in part determined by its respiration rate, *i.e.*, the more active a cell is metabolically, the greater will be the accumulation of salts, other things being equal. If growth rates can be used as an index of metabolic activity, it seems that the Kailua meristems are at a lower level of metabolism than those at Waipio and that the cause of the poorer correlations, when the data of the two places are combined, may be related to that fact. Thus for example the *error of estimate* for the relation between the green-leaf cane blades and the green top at Kailua is .0938; that at Waipio, .0805, and when the two populations are combined, the error of estimate is .0900. The *error of estimate* for the relation between the growing tissue at Kailua is .1527, at Waipio, .1642, but when the two are combined, it is .1878. Here the error of the combined plots is considerably increased indicating in this case that the Kailua and Waipio populations do not overlap each other as in the other comparisons and that another factor attributable to the locale has been introduced, but one which does not affect the correlations of other parts.

One other problem needs to be examined before ending this portion of the paper. Yuen and Hance (15) in collecting leaf material for nitrogen determinations have adopted the very simple procedure of using an ordinary paper punch and collecting disks of leaf-blade tissues. Because of its simplicity it may be desirable to use that method if it can be shown that it yields reliable correlations. To test this point, on April 8, 1942 a special collection of cane plants (32–8560) of several different ages was made, and separated into parts as above. In addition leaf punches were taken from the elongating cane blade and green-leaf cane blade samples, respectively. The relation between the nitrogen levels of the green top of the plant and those of the two blade samples as well as those of the leaf punches are shown in Table IX.

TABLE IX

t VALUES—GREEN TOP VS. BLADE AND LEAF-PUNCH SAMPLES

(All values highly significant)

Tissue	Green top
Elongating Cane:	
Whole Leaf Blades	12.15
Leaf Punch	9.44
Green-leaf Cane:	
Whole Leaf Blades	7.50
Leaf Punch	7.38

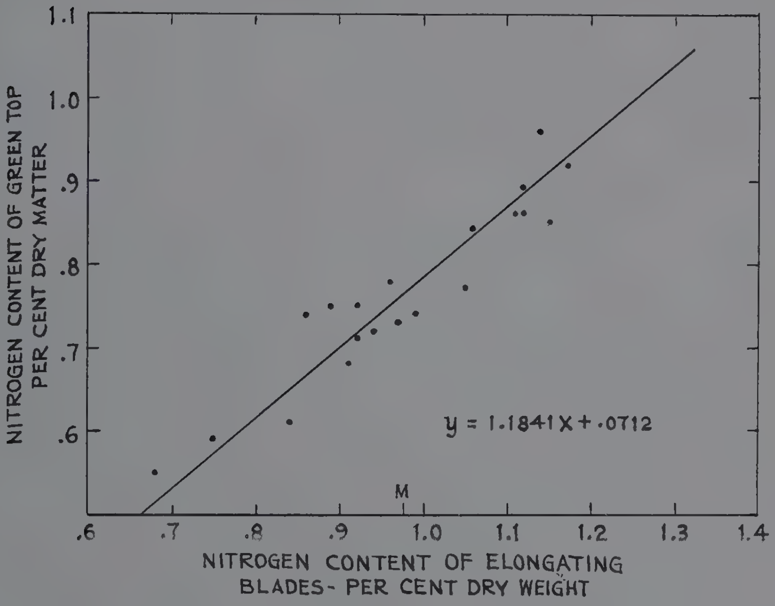

Fig. 7. Linear regression between the total nitrogen of the green top and the elongating cane blades (32–8560).

In Figs. 7 and 8 are plotted the data about the regression lines showing the relation between the green top and elongating cane blades and the leaf punches of these blades, respectively. Judging from the *t* values in Table IX and the excellent fit of the data to the lines in Figs. 7 and 8, it seems quite clear that although the leaf punches are not quite so good as the whole leaves, they are wholly satisfactory and can be used with a great deal of confidence.

Conclusion of Part I

Because of the high *t* values obtained for both the elongating cane blades and the green-leaf cane blades, it is apparent that either tissue can be adopted as an index to the nitrogen levels of the whole plant and the green top. However, in many cases the green-leaf cane blades are somewhat superior to the other blade samples. That this may be the result of an artifact is possible. The very same

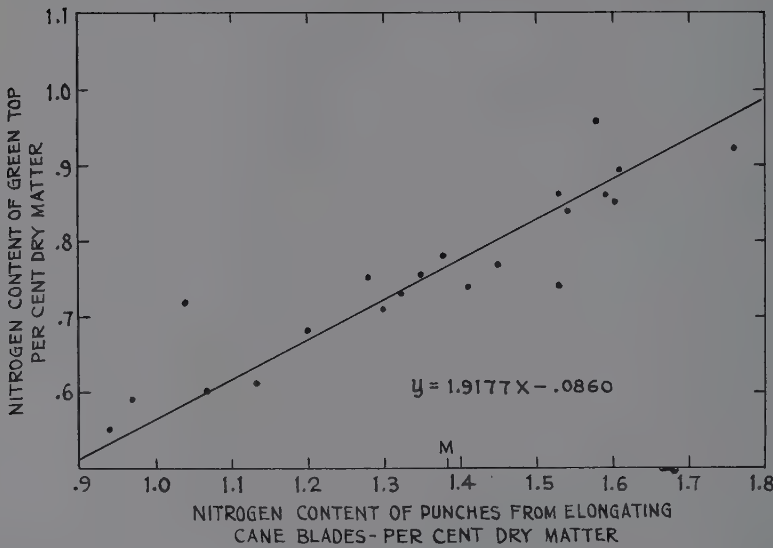

Fig. 8. Linear regression between the nitrogen content of the green top and punches of green tissue taken from the elongating cane blades of Fig. 7 (32–8560).

number of leaves of the elongating cane blades is taken each time while the number of the older leaves varies from season to season. In effect this variable was eliminated in compiling the data of Table IX in which case the t values were better for the elongating cane blades.

It is necessary, however, before making the final selection of an index tissue to wait until similar statistical studies can be made with reference to phosphorus and potash. It will be remembered that the sheaths of the elongating cane leaves were superior to those of the green-leaf cane blades as indices of the moisture level (3). But whether the one tissue or the other is used, a high order of confidence can be had in the value of the results.

The meristematic and elongating tissues of stems and leaves of the ratoon crops, *i.e.*, those crops controlled according to the levels indicated by the leaf blades, show good correlations. It appears, however, that the nitrogen level of these growing tissues is influenced by local influences other than the nitrogen levels of the plant, and hence must be studied further in that light.

Part II

Quantities of Nitrogen Contained Within a Crop Through Its Cycle

In conducting the field studies rather complete growth measurements were taken from the time the crop was 1 to 2 months old until it was harvested. These measurements included rates of elongation, leaf emergence, leaf drop and, finally, the circumference of the various internodes. These measurements were made on twenty pilot plants in each plot and, of course, the same pilot

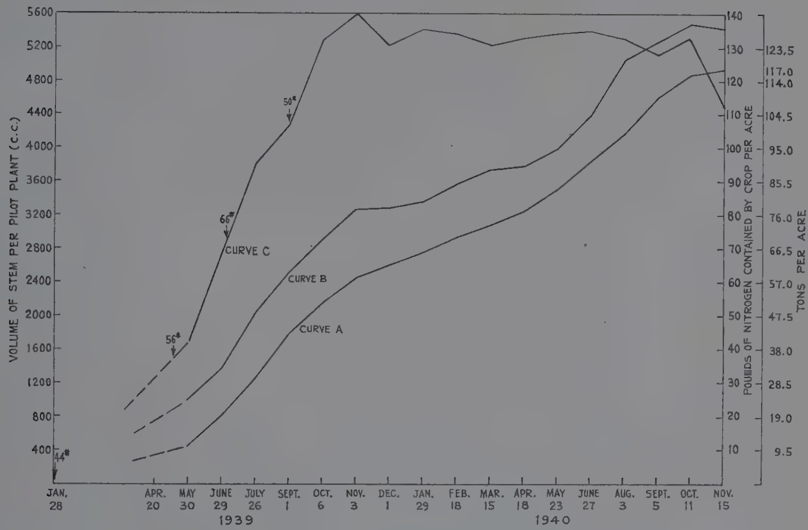

Fig. 9. Growth and nitrogen record for Waipio Plot C. Curve A when read off the left-hand axis represents the accumulating volume of stem per pilot plant. When read off the outside right-hand axis, it represents the accumulating tonnage of millable cane per acre. Curve B represents the total tonnage per acre of millable cane and green portions and is read off the outside right-hand axis. Curve C represents the pounds of nitrogen per acre contained within the above-ground parts of the plants and is read off the inside right-hand axis. Arrows on Curve C represent time of nitrogen applications in amounts indicated per acre.

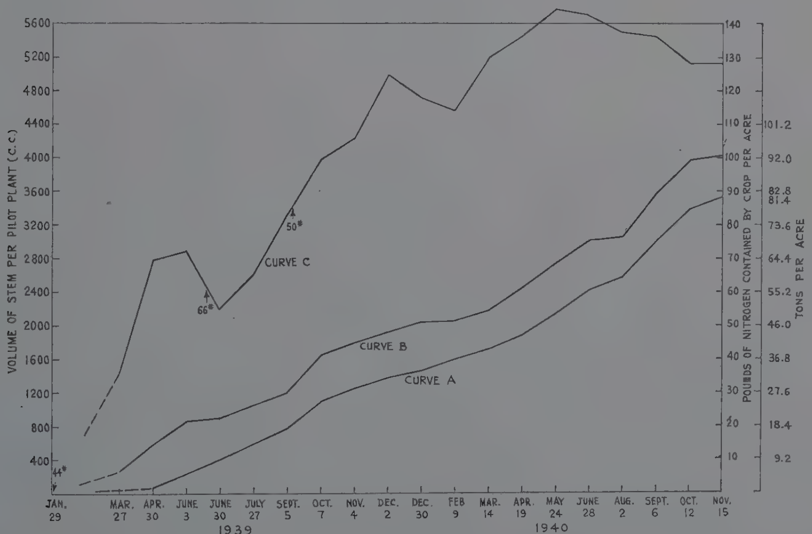

Fig. 10. Growth and nitrogen record for Kailua Plot C. (See legend to Fig. 9 for meaning of curves.)

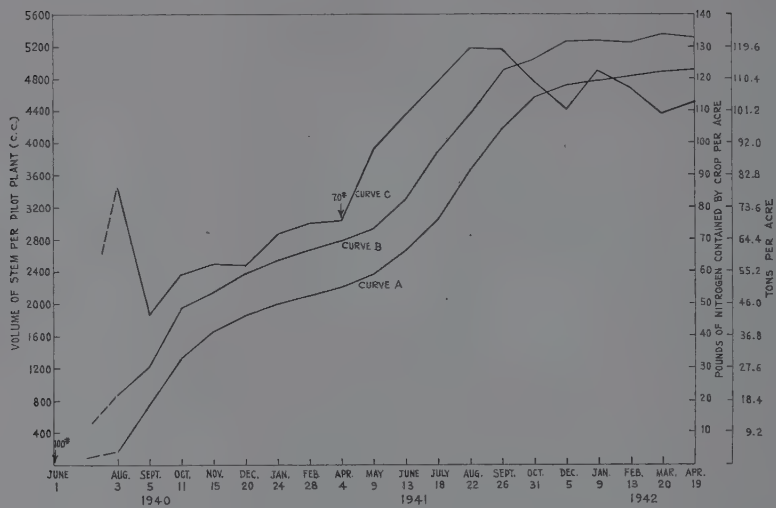

Fig. 11. Growth and nitrogen record for Waipio Plot RA. (See legend to Fig. 9 for meaning of curves.)

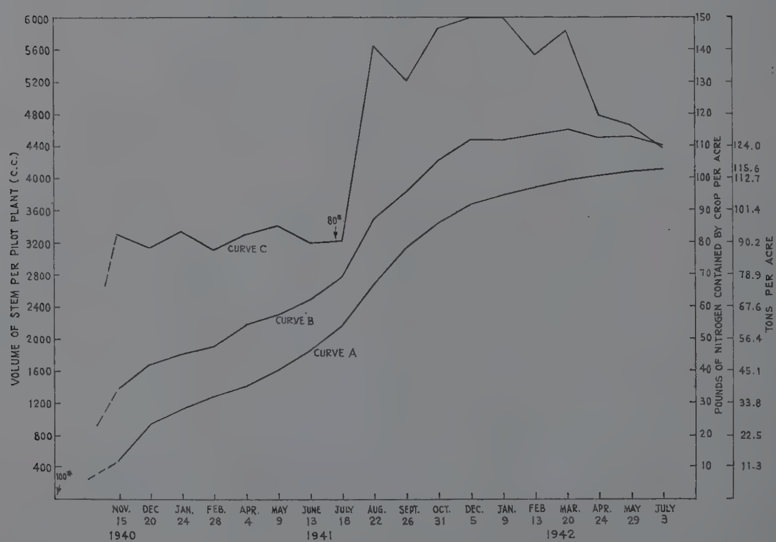

Fig. 12. Growth and nitrogen record for Waipio Plot RB. (See legend to Fig. 9 for meaning of curves.)

plants were used throughout the cycle. Occasionally a pilot plant is destroyed either by rats or breakage and has to be abandoned. Also, throughout the crop cycle field samples of whole plants were taken and analyzed for nitrogen, etc. At the end of the cycle the crop is harvested and weighed. These three measurements make it possible to calculate the tonnage of cane per acre at any one time in the crop cycle and also the amount of nitrogen in the crop at any one time. Composite graphs are shown in Figs. 9, 10, 11 and 12, and represent Plots C, Waipio and Kailua (9 and 10), two plant crops which were handled according to ordinary empirical plantation practice and Plots RA, RB, Waipio (11 and 12) ratoon crops subjected to controlled management. Unfortunately the ratoon crops at Kailua were so badly damaged by rats that the growth records are not reliable and hence are not included. The methods followed in the construction of these graphs will be described fully for Fig. 9, so that certain relatively minor reservations may be made relative to the reliability of the curves. To begin with, Curve A (Fig. 9) is plotted and represents the volume of the cane stem (average of the twenty plants) accumulating month by month until the crop is harvested. The cane included the green-leaf cane and all of the dry-leaf cane. It is reasonable to expect that the whole crop was growing at the rate indicated by Curve A. Now, at the end of the crop it was harvested and the yield of cane was 117 tons per acre. On the right-hand side of the graph, 117 is written at the end of Curve A, and the vertical axis is equally divided down to zero, accordingly. Now by projecting across to Curve A it is possible to obtain an estimate of the cane tonnage on the field month by month. But the green leaves and meristem contain much nitrogen and hence they must be included in the calculations of the total tonnage of both millable cane and green tissue. At this point the data obtained from the monthly collections are used. Each collection was made up of whole plants taken apart and weighed. From these data a ratio between the cane and the green tissues not included in the mill cane is obtained. Reading the tonnage on Curve A from the right-hand vertical axis and using the ratio of whole plant to millable cane, a value is obtained which when plotted for the crop cycle is Curve B. Curve B represents the total tonnage (cane and green top) per acre and, of course, is read off the right-hand vertical axis. Variations in the space between A and B represent variations in the amounts of green top tissues held by the crop. Knowing the nitrogen composition of the crop, month by month, it is a simple matter to calculate the amount of nitrogen in pounds per acre contained within the crop month by month. When the results of this calculation are plotted against pounds of nitrogen per acre Curve C is obtained. Arrows on Curve C represent the time applications of nitrogen were made to the field in the amount indicated per acre.

There are certain reservations which should be noted. Early in the crop there are many shoots which later are killed out in competition. Since Curves B and C are based on those shoots which make up the completed crops, they are lower than they should be during the first two to five months. Also, the exact nature of the curve during the very early months is not known and is simply drawn from the first determined point toward zero. Curve C must be fully understood, otherwise erroneous conclusions may be drawn. It simply represents an estimate of the amount of nitrogen in the crop at any one time. It does not mean necessarily that this is the total amount of nitrogen needed by the crop. Thus, the nitrogen of the

root system and that in the fallen leaves is not included. Just how much may be contained in these tissues is difficult to calculate since the nitrogen content of these tissues will vary considerably. When the roots are young and growing rapidly they will contain much more nitrogen than they will toward harvest. The quantity of nitrogen contained by the roots at harvest will depend upon the degree of senescence attained because of temperature, drying out, or because of the level of soil nitrogen. The roots of a well-matured crop possess relatively small numbers of active root tips and may therefore contain only small amounts of nitrogen. In the early growth, however, the roots are active and must contain considerable quantities. As the crop ages and the roots decline in activity, they probably give up much of their nitrogen to the top.

Something of the same type of processes are involved in dying leaves. It appears that a dead leaf, still attached to the plant, contains about one third to one half the nitrogen which it contained when fully active. How much of the nitrogen so lost moved into the plant and how much was leached from the leaf is not known. Both processes undoubtedly take place. Once the leaf has fallen, it decays. The soluble nitrogen as well as other solutes will be leached out by rain or by irrigation water and find their way back to the soil to be reabsorbed by the growing plant. Other processes would involve bacterial and fungal decomposition. How long before the nitrogen so taken remains in the bodies of the saprophytes would depend on a multitude of factors. But, no matter what the disposition of the nitrogen in the roots and "trash", varying amounts depending on many factors will not find their way back into the above-ground plants.

Nor does the amount of nitrogen indicated by Curve C show that that amount is the minimum amount needed. Thus, Fig. 9 shows 140 pounds contained within the crop which eventually yielded 117 tons of cane. But Fig. 10 reveals 144 pounds contained within the Kailua crop which ultimately yielded 81 tons of cane. To repeat, Curve C simply represents the amount of nitrogen contained by the particular crop whether necessary or not. Its usefulness consists in indicating the disposition of nitrogen through the crop cycle, and studies of such curves and experiments with them may ultimately aid in bringing the applications of nitrogen nearer to the actual needs of the plant.

Plot C—Waipio (Fig. 9):

The total amount of nitrogen added to this plot was 216 pounds applied as indicated. There was a very rapid absorption of it by the plant until November 3 when the maximum amount contained reached 140 pounds per acre. After this the nitrogen content remained more or less uniform until just before harvest when it dropped to 112 pounds of nitrogen contained in 117 tons of cane. In other words in the harvested crop there was about one pound of nitrogen per ton of cane. It should not be assumed that there was no further absorption of nitrogen after November 3. Even though the amount in the crop did not vary, actually as the leaves die and drop off they carry some nitrogen with them, but at least it seems that no more nitrogen is absorbed than is lost. It is also clear that as the plant grows it is using the nitrogen which is being released by the maturing tissues. (cf. Table II, note declining nitrogen percentage of the various internodes.) One

final observation can be made. Of the 216 pounds of nitrogen applied to the field, a maximum of 140 pounds was contained in the crop at any one time.

Plot C—Kailua (Fig. 10):

The total amount of nitrogen applied to this plot was 160 pounds. There was rapid absorption until May 24, 1940, but two periods of drought resulted in temporary losses. Drought causes a reduction in leaf area as indicated by the narrowing of the space between Curves A and B as well as a lower nitrogen level in the remaining leaves. At the peak the crop contained about 144 pounds of nitrogen and, as it approached harvest, it lost nitrogen until 128 pounds remained. Here we have a ratio of 128 pounds of nitrogen to 81 tons of cane, or about 1.6 pounds of nitrogen per ton of cane. Thus with a much smaller yield of cane, about as much nitrogen was consumed as at Waipio Plot C. Reference should be made to Table I, inspection of which will reveal the high levels of nitrogen remaining in the cane. Clearly the nitrogen added was excessive. Table III shows that at Kailua, reducing the amount of nitrogen to 100 pounds resulted in considerably reduced cane levels.

Were it possible to add the nitrogen fertilizer "just right," it should not be impossible to reduce the difference between that added and contained in the parts above ground, even though it would never be possible to exactly balance them. Waipio Plot C contained one pound of nitrogen per ton of harvested cane. Waipio Plot D contained 115 pounds of nitrogen at harvest and yielded 114 tons of cane, but at Kailua Plot C, 1.6 pounds of nitrogen were contained per ton of harvested crop. It would appear that at least a major part of the additional 0.6 pound was excessive.

Now by controlling the crop it should be possible to minimize the difference between the nitrogen added and the nitrogen needed by the crop, although forthcoming studies may reveal that reducing the nitrogen to the minimum may result in increased absorption of potash and therefore perhaps a false economy (2). But ignoring this possible factor for the present, Plots RA and RB at Waipio are cases in point. Plot RA (Fig. 11) was ratooned June 1, 1940, at which time 100 pounds of nitrogen were applied. There was a rapid growth and absorption up to August 3, at which time about 86 pounds were accounted for. As the crop closed in, and the older leaves died, the total amount of nitrogen dropped to 50 pounds. From this time on even though the growth was rapid, there was a slow accumulation up to 75 pounds on April 4. At this time the leaf tissues showed a drop in nitrogen and it became apparent that an application of nitrogen was necessary. The amount to be added was determined by striking a proportion between the light already experienced by the crop to the 100 pounds of nitrogen added as against the probable light to which the crop would be exposed until harvest. The answer was 70 pounds, which was then applied. Following April 4 there was a rapid absorption again from 75 pounds on April 4 to 130 pounds on August 22. Ignoring the residual nitrogen, of the 70 pounds added 55 pounds were recovered by the tops alone. Of the 170 pounds added, the crop at its maximum contained 130 pounds or about 76 per cent. At harvest the 113 tons of cane (15.2 tons of sugar) contained 112.5 pounds of nitrogen! Is this repeated ratio of one pound of nitrogen per ton of cane an accident? If it is not, it may constitute a valuable check for fertilizer

programs. Of the original 100 pounds (Fig. 8), only 75 pounds were in the crop on April 4. Just how much was contained in the dead leaves and roots is not known, but that and the 75 pounds represent the recovery of the 100 pounds. It is possible that had a smaller application been made at the start, there would have been greater recovery. The second application increased absorption to 130 pounds following which there was a decline even though growth was still very active. Now, since the application of the second quantity of nitrogen was calculated on the basis of the original 100 pounds, it follows that if that was too high, the second application would also be somewhat higher than necessary.

Waipio Plot RB (Fig 12) was handled in a somewhat similar fashion. It was started August 28, 1940, at which time 100 pounds of nitrogen were added. Growth was very rapid until checked by winter temperatures, but during that period about 80 pounds were held by the above-ground parts of the plant and appeared to be sufficient for the growth of the crop until some time in May 1941, when the leaf nitrogen began to drop off rapidly (cf. Table V—Elongating cane blades). This starvation period was deliberately prolonged as a hardening period until July 11 at which time the leaf nitrogen was very low. (Incidentally, through this period of hardening, full irrigation had been maintained.) On July 13 the calculated amount of nitrogen was determined to be 80 pounds which was then applied. The absorption of the new addition was apparently instantaneous, for by the next sampling the nitrogen level rose to 140 pounds and the response in growth was also rapid. It is interesting to observe (Table V) that the rise of nitrogen levels is noted almost solely for the top of the plant with the mature, old cane getting little or none of the fertilizer applied.

The maximum quantity of nitrogen contained by the tops reached 152.9 pounds (December 5, 1941), about 85 per cent of the 180 pounds, and remained at high levels until the crop was being prepared for harvest. A rapid decline in the amount of green tops caused the reduction in the amount of nitrogen to 109 pounds at harvest (115.6 tons of cane per acre and 16.26 tons of sugar).

At Waipio Plot C of the 216 pounds applied, 140 pounds were found in the crop, or 65 per cent of the total. In Waipio Plot RA of the 170 pounds applied, 130 pounds or 76 per cent of the total was found in the crop. At Waipio Plot RB of the 180 pounds applied, the crop contained 152.9 pounds or about 85 per cent. To be sure, these calculations ignore residual nitrogen. But in the second and third plots, more sugar was obtained than from Plot C with fewer pounds of nitrogen added. Here, not only is there a saving on the fertilizer and its application, but there is an improvement in yield of sugar. How much this procedure can be refined and how far the amount of nitrogen can be reduced will depend upon more work, but these data indicate the possibilities.

Conclusions for Part II

Figs. 9-12 reveal many points of interest. In Fig. 9 Curve C shows the absorption of nitrogen resulting from empirical applications of nitrogen fertilizers. Judging from the steepness of the curve while applications were being made, there was no apparent need to make each additional application at the time it was made, and apparently the final application could have been saved. Fig. 10 Curve C shows the same situation for the Kailua crop. Here, however, following the

initial addition of 44 pounds, there was a recovery of 72 pounds, indicating quantities of residual nitrogen were being absorbed. But the most striking part of this figure is that the crop which yielded 81 tons of cane contained more nitrogen than the much larger crop at Waipio. If an attempt is made to mature such a crop during periods of high temperatures and abundant rainfall, quality is certain to be poor. In this case the quality ratio was nearly 12. On the other hand, such a crop, if it is to be harvested during periods of drought and low temperature may yield satisfactory quality. In contrast to these two crops are those shown in Figs. 11 and 12. In these the nitrogen was applied more as the crop seemed to require it, resulting in a definite change in the slope of the curve following the addition. Furthermore, the apparent recovery of applied nitrogen was better in each case than where the nitrogen was applied empirically. Another point of interest is the speed of absorption of the second application shown in Figs. 11 and 12. Fig. 12 shows a tremendous rise in the nitrogen within the one collection period. The crop had exhausted the soil nitrogen and when the application was made in the middle of July the soil was warm and moist. Absorption under such conditions is excellent. Fig. 11 shows the second absorption to be much slower. The ascent of the curve extends over several sampling periods. Very probably the more important limiting factors here were the lower soil temperature and lesser root activity early in April.

Finally, one might add after viewing these cases, how different each one is, and how essential that applications both in quantity and time be made as the crops indicate the need for them.

Summary

1. Fourteen plots of sugar cane were grown under field conditions at Waipio and Kailua including four plots of plant cane at each place and three of ratoon cane.

2. Plants from each of the plots were collected at approximately monthly intervals, separated into their various parts and analyzed for total nitrogen.

3. The data so accumulated are subjected to statistical treatment to obtain the most reliable nitrogen index tissue.

4. The elongating cane blades and the green-leaf cane blades are both wholly satisfactory as indices. The same may be said of leaf punches taken from these leaves.

5. The amounts of nitrogen contained within each of four crops are calculated and discussed in relation to the amounts of nitrogen fertilizer applied.

Literature Cited

(1) Clements, Harry F., 1940. Integration of climatic and physiologic factors with reference to the production of sugar cane. The Hawaiian Planters' Record, 44: 201–233.

(2) ——————, Martin, J. P., and Moriguchi, S., 1941. Composition of sugar cane plants grown in deficient nutrient solutions. The Hawaiian Planters' Record, 45: 227–239.

(3) ——————, and Kubota, T., 1942. Internal moisture relations of sugar cane—the selection of a moisture index. The Hawaiian Planters' Record, 46: 17–35.

(4) Hoagland, D. R., and Davis, A. R., 1929. The intake and accumulation of electrolytes by plant cells. Protoplasma, 6: 610–626.

(5) ——————, ——————, and Broyer, T. C., 1936. General nature of the

process of salt accumulation by roots with description of experimental methods. Plant Phys. 11: 471–508.

(6) Lagatu, H., and Maume, L., 1932. Application du diagnostic foliare: il suggère contrôle et limite le redressement alimentaire d'une vigne mal nourrie. Compt. Rendu. 194: 812–814.

(7) ————, and ————, 1933. Composition comparée, chez la vigne, de feuilles homologues prises respectivement sur des souches fructifères et sur des souches privées de leur grappes. Compt. Rendu. 196: 1168–1170.

(8) ————, and ————, 1933. Composition comparée de la matière sèche de feuilles homologues des rameaux fructifères et des rameaux naturellement steriles d'une vigne. Compt. Rendu. 196: 1445–1447.

(9) Pierre, Isidore, 1869. Fragment d'études sur les epoques d'assimilation des principaux éléments dont les plantes se composent. Compt. Rendu. 66: 1526–1532.

(10) Steward, F. C., Berry, W. E., and Broyer, T. C., 1936. The absorption and accumulation of solutes by living plant cells. VIII. The effect of oxygen upon respiration and salt accumulation. Ann. Bot. 50: 345–366.

(11) Thomas, Walter, 1937. Foliar diagnosis: Principles and practice. Plant Phys. 12: 571–599.

(12) ————, and Mack, Warren B., 1938. Foliar diagnosis in relation to development and fertilizer treatment of the potato. Jour. Agr. Res. 57: 397–414.

(13) ————, and ————, 1939. The foliar diagnosis of *Zea mays* subjected to differential fertilizer treatment. Jour. Agr. Res. 58: 477–491.

(14) ————, and ————, 1939. Foliar diagnosis: Physiological balance between the bases lime, magnesia and potash. Plant Phys. 14: 699–715.

(15) Yuen, Q. H., and Hance, Francis E., 1939. Nitrogen in the cane leaf. The Hawaiian Planters' Record, 43: 163–207.

A Search for Guidance in the Nitrogen Fertilization of the Sugar Cane Crop

Part I—The Plant Crop

By R. J. Borden

Measurements and analyses made on samples from sugar cane crops which had been differentially fertilized with nitrogen have pointed out a number of effects from the nitrogen treatments upon the yields and the composition of the crop. These may be summed up as follows: to a plant crop of 32–8560 cane which had already been given 100 pounds of nitrogen per acre, an additional 60 pounds applied in June when the crop was 10½ months old had the following effects at the final harvest 10 months later: (a) *definitely increased* (1) *the percentage of nitrogen in the total dry weight, in the leaf-punch samples, and in the crusher juice,* (2) *the percentage of chlorophyll in the green-leaf blades,* (3) *the tons per acre of reducing sugars, and* (4) *the pounds of nitrogen per acre in the dry weight;* (b) *possibly increased* (1) *the total green and dry weights,* (2) *the percentages of tops and of moisture in green weight,* (3) *the percentage of reducing sugars,* (4) *the total tons of sucrose and of total sugars, and* (5) *the tons of millable cane and of commercially recoverable sugar;* (c) *decreased the percentage of phosphate in the total dry weight;* (d) *possibly decreased the percentages of sucrose and of total sugars; and* (e) *had no effect on the yield per cent cane.*

To a comparable crop which had received 160 pounds of nitrogen, an additional 60 pounds applied in June at 10½ months had these effects on the crop harvested at 20½ months: (a) *definitely increased* (1) *the percentage of nitrogen in the total dry weight and in the crusher juice,* (2) *the percentage and the tonnage of reducing sugars;* (b) *possibly increased* (1) *the percentage of nitrogen in the leaf-punch samples,* (2) *the pounds of nitrogen in the total dry weights, and* (3) *the percentage of sucrose and of total sugars;* (c) *possibly decreased the yield per cent cane and the commercial sugar yield; and* (d) *probably had no effect on* (1) *the total green and dry weight, or the yield of millable cane,* (2) *the per cent tops and moisture,* (3) *the chlorophyll in the leaf blades,* (4) *the percentages of* P_2O_5 *and* K_2O *in the total dry weight, or* (5) *the tonnages of sucrose and of total sugars.*

The many data have been studied for their relationships, and specific values have been recorded for further affirmation or denial. Chief interest centers in the fact that the differences in the nitrogen treatments were quickly identified by the changes in the percentages of nitrogen as found in either samples of the total dry weight, of the leaf-punch samples, of the leaf blades, or of the crusher juices. Thus any one of these analyses was shown to reflect the nitrogen supply which had been available up to the time of sampling. The specific percentage figures which were associated with the crop at 10½ months will be watched further to determine whether they can indicate an adequacy or an inadequacy in nitrogen concentration to support optimum yields for another 10 or 12 months of the growth period.

CONTENTS

Introduction

Probably no plant food which is made available to sugar cane crops through commercial fertilizers has received and deserved more consideration than nitrogen. Sugar plantation men everywhere recognize the value and the need for nitrogen and are quick to recognize its deficiency in the field through leaf symptoms. If these nitrogen deficiency symptoms are identified early enough in the crop's development, it is an easy matter to correct them quickly by making an application of a soluble nitrogen fertilizer, but if the crop has lodged, then an economic correction is more difficult and often impractical.

To use nitrogen fertilizer efficiently, one must recognize how exacting the cane plant is with respect to this nutrient: too little produces too little growth whereas too much means the wrong kind of growth. In a dry soil it remains unavailable until moisture comes, while in a water-logged soil the sluggish root system cannot pick it up. Under certain soil conditions it can be leached beyond the root zone. Weeds will compete for it. Used where organic materials with high carbon-nitrogen ratios have gone into the soil, it is pounced upon by the soil organisms, and its release from this microorganic complex, which is probably never complete, may come at the wrong time—too late.

Sugar cane grown continuously on the same areas without periods of fallow is almost invariably fertilized with nitrogen. Present-day field practices have evolved largely from years of experimental work and the careful observations and experience of good cane farmers; a contributing factor has undoubtedly been the results from local research investigations. This research continues for there are still many moot points involved in finding that procedure for nitrogen fertilization of the sugar cane crop which will produce the maximum sugar yield from a minimum of cane stalks harvested. Thus the present study is another effort to obtain information that will lead to better nitrogen fertilization for the sugar cane crop.

The Problem, Plan, and Procedure

1. The Problem:

In common with many other investigators of soil and plant relationships, we are especially desirous of finding some index of plant or soil or both which can be used to guide our nitrogen fertilization. Former soil studies alone have not given us as satisfactory an answer for nitrogen needs as they have indicated for phosphate and potash, and some of us now lean more toward plant studies, following the suggestions of those scientists who have made their plants tell them whether or not there is a need for more nitrogen.

A sugar cane crop which is harvested at 22-24 months is made up of a some-

what complex group of stalks which started to grow almost anytime within the first 16 to 18 months, and the stalk-age composition of every crop will vary. Thus although those stalks which get their start during the first couple of months usually make up the larger part of the crop at harvest, this condition can actually vary considerably. Cornelison (2) has recorded a case in which 35 per cent of the H 109 stalks found at harvest had not started their growth until after the stalk census was made at 4 months. In another instance Cornelison (3) states: "At 24 months, POJ 2878 . . . the entire stand was secondary growth".

Because of the growth habits of our best cane varieties, the stalks are usually recumbent some 10 to 12 months before they are harvested, and after this recumbency it is difficult and often impractical to apply more nitrogen fertilizer which might be needed to correct a late-identified deficiency, unless it can be distributed through the irrigation water. Furthermore, if this late application of nitrogen is a large one or makes the total amount applied excessive, and is followed by subnormal sunshine or a relatively short period of active growing time before harvest, then there is the likelihood that it will not be completely assimilated and that a poor cane quality and sugar recovery will be the result. Thus it is essential that when an adjustment of a partially completed nitrogen fertilizer practice is needed, it must be made during the early part of the growth period while it is still physically possible to make another fertilizer application.

More specifically our actual problem then is somewhat like this: On the basis of past experience, skilled sugar cane planters can usually guess within 50 or 75 pounds of the optimum amount of nitrogen that a specific crop of their cane will need. But it is this guess which can make a difference between a profit and a loss for the planter. Guidance to make this guess less uncertain will need to be at hand some 8 or 12 months before the crop is to be harvested, and at this time the crop will already have been given a basic application of perhaps 75 to 125 pounds of nitrogen per acre, and will be well established and perhaps "covered in". It then becomes necessary to decide whether another 50 to 75 pounds or more will be needed, so that we can get this applied before the cane "goes down". If we apply too little at this time, we may limit the final cane yield and come out with a lower sugar yield than we might have had if the cane crop had been larger; if we apply too much at this specific time, then we stand the chance of producing a lot of extra cane tonnage from which the sugar recovery will be made at a monetary loss. In either instance we must gamble on the weather conditions of the subsequent 10-12 months which will influence the completeness with which this additional amount of nitrogen will be assimilated before harvest time comes.

Furthermore it is somewhat doubtful if we can disregard the contribution of nitrogen which the soil itself can continue to make to the cane crop during the second half of its relatively long growth period, and this contribution can complicate our interpretation of the subsequent nitrogen needs of the current crop which are based on plant analyses alone that were made earlier.

From the foregoing it is apparent that our search for a nitrogen index from

the cane crop itself, before the crop "goes down", is a worthy one, but one that is fraught with interactions.

Since there has been considerable interest shown in foliar diagnosis of plant deficiency symptoms, and as a local technique of leaf-punch sampling for nitrogen analyses seemed to offer promise of having the cane crop reveal its nitrogen requirements concurrently with its development, it seemed advisable to study the results from leaf-punch nitrogen analyses made from active cane leaf samples taken periodically throughout the growing period of crops which had been similarly fertilized with nitrogen in their earlier months and subsequently given differential nitrogen treatments; all with the hope that the leaf-punch nitrogen index would be found to supply the guide to optimum sugar yields from controlled nitrogen fertilizations. Concurrently an opinion was expressed that knowledge of the total nitrogen in samples of the entire crop, and perhaps of total nitrogen in the crusher juices might be what we were looking for; and in order to learn how differentials in nitrogen fertilization can affect the development and composition of the crop at various ages, current sugar analyses were very desirable contributions.

2. *The Plan:*

Following conferences between staff members who were to have a part in the investigation, a Grade A field experiment (Waipio No. 108 ATN), from which cane samples could be taken periodically for specific analyses, was proposed for installation in Waipio Field L. A simple plan was agreed upon wherein there would be (*a*) three levels of nitrogen fertilization, and (*b*) one difference in the time of making the last application for one of these total amounts which were prescribed. The specific plan of fertilization was then set up as follows:

Plot identity	Appl. No. 1 7/26/40 Lbs. P_2O_5	Appl. No. 2 9/16/40 Lbs. N	Lbs. K_2O	Appl. No. 3 11/15/40 Lbs. N	Appl. No. 4 3/17/41 Lbs. N	Appl. No. 5 6/23/41 Lbs. N	Total per acre Lbs. N	Lbs. P_2O_5	Lbs. K_2O
A	100	40	100	60	0	0	100	100	100
B	100	40	100	60	0	60	160	100	100
C	100	40	100	60	60	0	160	100	100
D	100	40	100	60	60	60	220	100	100

For additional information, chiefly observational, a few extra plots were included which received no nitrogen except that which they could get from the soil itself; these "X" plots were given phosphate and potash similarly to those which received nitrogen fertilizer.

Since the area selected for the field test had been used for seedling testing for several years and was expected to show normal variability, 8 replicates of the 4 main treatments were specified, and a block arrangement of plots was used so that the results could be treated statistically by the analysis of variance. The layout is shown in Fig. 1. Plots in 7 of the blocks, each carried fifteen 60-foot rows of cane; in the eighth block only 12 rows per plot were available. One row was left unplanted between the sides of adjacent plots to reduce the "border effect" and to facilitate sampling and harvesting; a 7-foot space carrying the watercourses served a similar purpose between the ends of abutting plots.

Within each plot, 6 rows of cane (cross-hatched areas in Fig. 1) were desig-

nated as the "sampling station" from which all preharvest cane samples prior to the final field harvesting were taken; this was prescribed so that there would be no interference with the cane in the rest of the plot from which we wished to secure final and confirmatory yield data at the age of about 21 months.

From each of these sampling stations, *all* cane stalks growing within a 5-foot

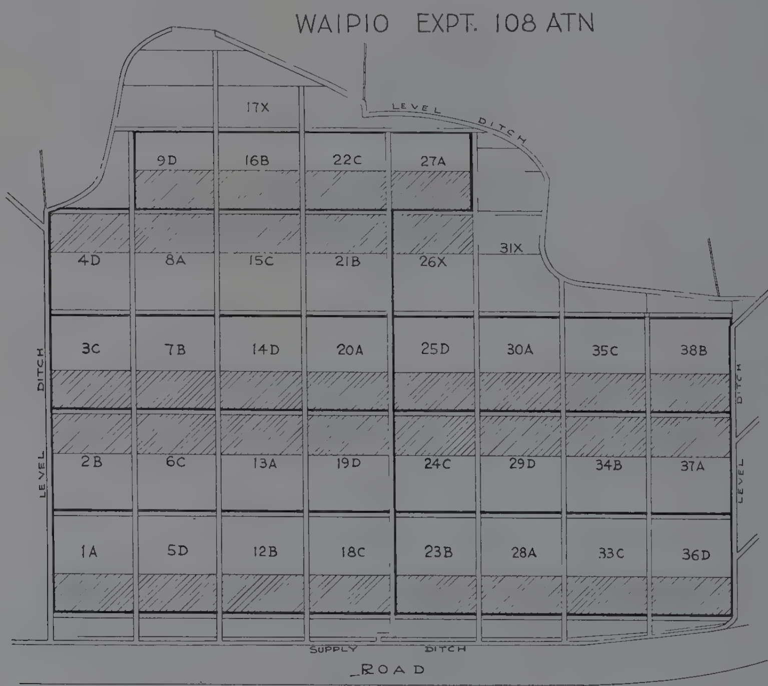

Fig. 1.

section of row were scheduled to be cut out at each of the following ages: 3½, 5½, 7½, 8½, 9½, 10½, 11½, 14½, 17½ and 20½ months. Thus the total plant material from a 5-foot section of cane row selected at random was our individual plot sample of the cane crop which was thereafter to be sub-sampled, prepared, and analyzed for certain constituents.

3. *Field Culture:*

After a thorough job of soil preparation and the laying out of the plots, seed of the variety 32–8560 was cut and planted during the week subsequent to July 26, 1940. Superphosphate was applied with the seed in every planting furrow and an immediate irrigation was given.

Subsequent germination in several of the first fifteen plots was exceptionally

poor and a heavy replanting* was made at 3 weeks after the original planting in order to insure a full stand in all plots as early as possible.

Plot no.	Treatment	Per cent replant	Final yield TCA	Avg. yield TCA for treatment
1	A	70	112.9	110.9
2	B	10	129.4	120.0
6	C	10	117.7	120.2
7	B	15	116.3	120.0
8	A	20	103.1	110.9
9	D	20	110.6	122.7
12	B	70	119.6	120.0
13	A	65	110.6	110.9
14	D	50	122.4	122.7
15	C	30	118.0	120.2

After the first few rounds of irrigation, subsequent irrigation intervals were maintained at 250 elapsed day-degrees until January 21, 1942; thereafter, no further irrigations were made, and there was a total rainfall amounting to only 5.21 inches between this date and the final harvest.

Ammonium sulphate and muriate of potash were applied by hand on the cane row as scheduled, and an adequate weed control was maintained until the crop was well covered in.

4. *Observations at Periodic Harvests:*

The following observations which were recorded at the periodic harvests should be made a matter of record, since they may have a bearing on some of the measurements and interpretations which were made.

At first preharvest, at 3½ months: (1) The cane growth in the 32 plots which had received 40 pounds nitrogen to date was quite variable although the stand was excellent and stooling was heavy. (2) Sections of rows which had been heavily replanted were avoided when the cane sample was taken. (3) The color and growth of cane in "No N" or "X" plots were quite comparable with that in the N-fertilized plots.

At second preharvest, at 5½ months: (1) Considerable variation in development was still noted although growth in general had been exceptionally rapid. (2) The "No N" plots showed the yellowish-green leaf-color symptoms of nitrogen deficiency.

At third preharvest, at 7½ months: (1) All fertilized plots appeared strikingly uniform in appearance, stand, and stalk size. (2) Rapid growth had continued and stalks were still erect. (3) There had been a heavy mortality of the smaller shoots—evidently shaded out.

At fourth preharvest, at 8½ months: (1) The total green weight samples contained a very few small "second-season" shoots. (2) The millable cane was quite definitely "sweet to taste".

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* That this replanting was effective, may be seen from the fact that these plot yields, on their gross area basis at final harvesting were not significantly different from their respective treatment averages, *e.g.*:

At fifth preharvest, at 9½ months: (1) A considerable number of suckers had made their appearance in the cane samples harvested. (2) The cane had now "gone down" in the "C" and "D" plots especially.

At sixth preharvest, at 10½ months: (1) The cane was now recumbent in all fertilized plots. (2) The cane sample included some sucker growth.

At seventh preharvest, at 11½ months: (1) The millable cane on large suckers made its first appearance in the cane samples.

At eighth preharvest, at 14½ months: (1) Big suckers with considerable millable cane made up from ¼ to ⅓ of the cane samples at this harvest. (2) All canes appeared by taste to have very little sugar—they were definitely disagreeable to taste.

At ninth preharvest, at 17½ months: (1) All stalks were in the best physical condition of any yet harvested; uniform big healthy tops, no dead cane stalks, and all seemed to have recovered their sugar, as they were "sweet canes" again at this time.

At tenth preharvest, at 20½ months: (1) Physical condition of cane was very poor; heavy winds had damaged tops and broken some stalks; tops appeared small and dry; some dead or dying tops were noted. (2) Sound canes were very sweet.

At the final field harvest, at 21½ months: (1) Secured almost perfect burns as cane was very dry. (2) Stalks appeared sound, heavy, and full of sugar. (3) Very little dead cane actually found.

5. Experimental Procedure:

Soil samples were taken each month from the row middle in a series of "X" plots which received no nitrogen, and from a "D" series which ultimately received the highest total amount of nitrogen fertilizer given. These were analyzed for their available nitrogen content by both the Mitscherlich and the R.C.M. methods of analysis.

Leaf-punch samples were taken periodically from the cane in every sampling station, according to the accepted procedure, and subsequently analyzed individually for their percentages of total nitrogen.

At each preharvest after the crop from each 5-foot section of row had been cut out, the cane was weighed to secure its total green weight. It was then divided into two comparable portions—one of these was topped and the millable cane therefrom weighed and crushed in the Cuban A mill at Waipio, while the other portion was brought to Makiki and there subjected to further sub-sampling to reduce its bulk to an amount needed for the laboratory samples. In this sub-sampling procedure, great care was taken in sectioning and quartering the stalks, in cutting up the tops, and then in combining stalk and top segments in the proportion of their actual field weights to make certain that each laboratory sample was truly representative of the total cane sample harvested from each plot.

Laboratory samples of this total green weight were prepared for the determination by standard chemical methods of total nitrogen, chlorophyll, moisture, reducing sugars, sucrose, and total sugars; later, determinations of total phosphate and potash were also made. After the second preharvest, samples of young leaf blades

and sheaths were also gathered for subsequent determinations of nitrogen, moisture, and sugars.

Most of the measurements and analytical data have been carefully examined and studied by the "analysis of variance". Positional effects have been largely removed from the total experimental error, but the residual errors still remain quite high, and indicate very definitely the heterogeneity which is always encountered in dealing with valid samples of a crop of sugar cane taken from the field. Thus although the number of replicate cane samples which were taken for analyses was generally greater than most plant investigators have worked with, many of the averaged differences measured must carry the statistical term of "non-significance", and interpretations therefrom will only be made tentatively until further evidence is obtained. No reasonable explanation is being rejected however, simply because a verdict of non-significance from the samples studied warns that one cannot be sure that the recorded differences are really the effects from the different nitrogen treatments. Data from the 3 "X" plots upon which no nitrogen fertilizer was applied have not been included in the statistical analysis, and the "minimum differences required", which are found listed in the tables in the Appendix, have reference only to differences between the 4 treatments which received 100 pounds per acre or more of nitrogen fertilizer.

Basic Soil Analyses

1. *Initial Soil Analyses:*

After all plots had been laid out, 2 composite soil samples, each made up from 10 soil-auger borings, were taken to depths of 0-12 inches and 12-24 inches, respectively, from each plot. Chemical analyses of these showed that we had placed the field test on a soil which had the following important characteristics:

Measurements	Depth 0–12″		Depth 12–24″	
	Average*	Range	Average*	Range
% total nitrogen	.114	.080 to .126	.084	.069 to .097
% total carbon	1.367	1.185 to 1.508	.852	.695 to 1.182
Ratio C/N	12.0	10.2 to 16.5	10.1	8.9 to 14.2
% available N (R.C.M.)	.0016	.0008 to .0037	.0006	.0005 to .0008
% available P_2O_5 (R.C.M.)	.0040	.0012 to .0090	.0005	.0004 to .0015
% available K_2O (R.C.M.)	.0031	.0025 to .0040	.0009	.0008 to .0012
P_2O_5 fixation index	65	50 to 85	90	80 to 90
pH	6.6	6.3 to 6.9	6.7	6.3 to 6.9

* From separate analyses of 35 soil samples.

From a subsequently taken composite soil sample, volume weight was found to be 1.06, for soil from either depth. Thus the total organic matter was estimated (C x 1.7) to be close to 68,000 pounds per acre surface-foot of soil, and total nitrogen was calculated at approximately 3,300 pounds per acre, to a depth of 12 inches. Hence this soil would not be considered a "high" nitrogen soil and response to nitrogen fertilization should be quite definite.

Biological tests (Mitscherlich) of soil fertility made on 2 composite soil samples taken within the experimental area indicated averages of the principal nutrients to be available in amounts as follows: 60 pounds nitrogen, 247 pounds phosphoric acid, and 633 pounds potash per acre.

A study of the soil analyses data from those 16 plots which received a total of 160 pounds of nitrogen, to find their relationships with their final cane yields, has shown no significant correlations. Correlation coefficients (r) between final yields and certain nitrogen measurements were calculated as follows:

(a) Per cent total nitrogen in soil and tons cane per acre: $r = -.40 \mp .21$
(b) Per cent available nitrogen in soil and tons cane per acre: $r = -.42 \mp .20$
(c) Carbon-nitrogen ratio of soil and tons cane per acre: $r = +.06 \mp .25$

2. Subsequent Soil Analyses:

Each month during the cropping period, soil samples to a depth of 12 inches were taken from each of 16 points located midway between the cane rows from plots of both Treatments X and D. Tested by a biological method (Mitscherlich) for their content of available nitrogen, we have a fair picture of the manner in which this soil was able to maintain a supply of nitrogen for this sugar cane crop. This is nicely shown in Fig. 2. The increase in available nitrogen during the first

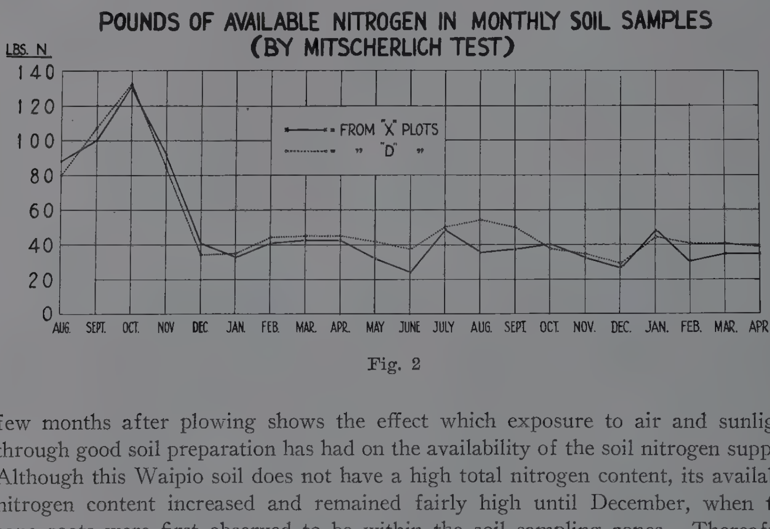

Fig. 2

few months after plowing shows the effect which exposure to air and sunlight through good soil preparation has had on the availability of the soil nitrogen supply. Although this Waipio soil does not have a high total nitrogen content, its available nitrogen content increased and remained fairly high until December, when the cane roots were first observed to be within the soil sampling zones. Thereafter there was very little fluctuation, but apparently there was some soil nitrogen which continued to be available even within that soil zone which carried many active cane roots.

Treatment Effects

1. On Total Green Weights (Fig. 3). See footnote *:

In general there was a direct response to the amounts of nitrogen applied, *i.e.*, the more nitrogen applied, the more the total vegetative growth. The 60 pounds

* The complete legend for this graphical presentation, identifying treatment, total pounds of nitrogen supplied, and month in which the final 60 pounds of nitrogen were applied, is shown on Fig. 3, and this same legend, somewhat abbreviated, is used consistently hereafter in all except Figs. 17, 20, 21, and 22 which have their own specific legends.

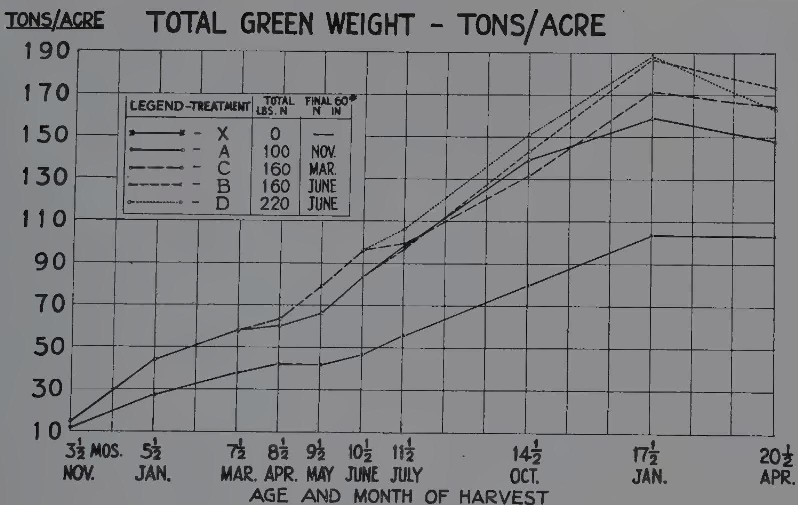

Fig. 3

of nitrogen applied in March (Treatment C) to crops which had already had 100 pounds were almost immediately effective and had significantly increased the total green weight by May; a further 60-pound application in June (Treatment D) maintained this accelerated growth rate through January, whereas production fell off somewhat when this June application was not made (Treatment C). Similarly, to that cane which had received only 100 pounds of nitrogen by June, an additional 60-pound application (Treatment B) produced increased tonnage thereafter.

The nature of this production of total vegetation is interesting. It was exceedingly rapid, even during the winter months—November to January—when the crop was only 3½ to 5½ months old. It apparently slowed down during March, April, and May but picked up again in early summer, and then maintained a rather constant rate throughout January. This constant increase in total green weight from June through January, especially by Treatments B and D which received nitrogen in June, is somewhat contrary to opinions that have been formed on the basis of growth measurement studies which usually show a greatly reduced rate of elongation by cane that is over one year old after September or October. After January subsequent development was apparently influenced by the "drying-off" period preceding harvest.

2. On Percentage of Tops (Fig. 4):

In this consideration, the top was defined as that portion of the stalk upwards from the growing point, plus all of the green leaves.

All plots showed a sharp decrease in their percentage of tops but it is quite doubtful that the differences noted between the treatments are significant. Between the ages of 5½ and 11½ months there was a reduction from about 40 to 20 per cent, and in the next 6 months a further decrease from 20 to approximately 10 per cent. This percentage of tops from the nitrogen-fertilized canes had decreased to between 8 and 9 per cent at the last preharvest at 20½ months.

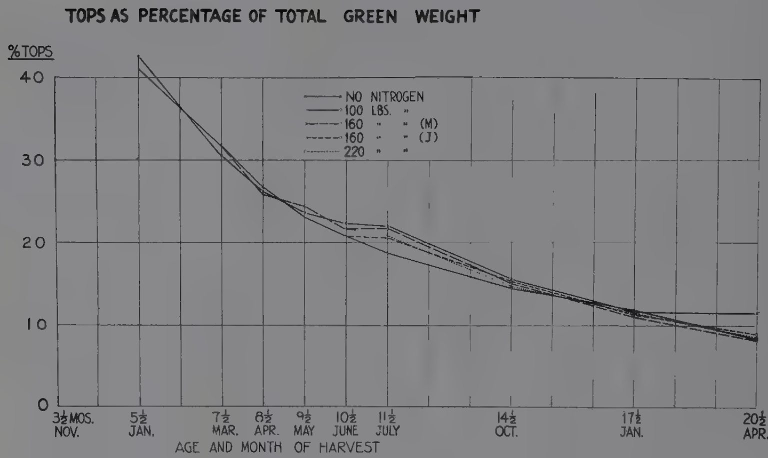

Fig. 4

3. On Per Cent Moisture in Total Green Weight (Fig. 5):

The effect of the nitrogen differentials on the per cent moisture in the crop is quite apparent. The higher nitrogen applications have consistently produced cane crops with a higher moisture content; this fact was particularly significant in the October harvests which apparently reflected combined effects with the high temperatures between July and October. It may also be an effect from the larger numbers of suckers which appeared in the October harvest on those plots which had received additional nitrogen in June.

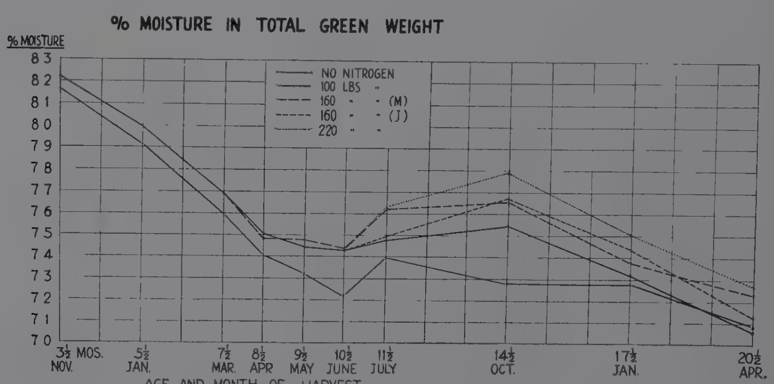

Fig. 5

Up to the age of 5½ months, during the winter months, the young crop of cane was very succulent, carrying about 80 per cent moisture. Between April and July,

the moisture content remained around 75 per cent, but during the hot days of late summer there was a definite increase. This was followed by a decrease as the second winter approached, and a further decrease during the drying-off period preceding the April preharvest at 20½ months.

4. On Total Dry Weight (Fig. 6):

The picture for total dry weight does not differ widely from that of total green weight. The 60-pound nitrogen application made in March to a crop which had already received 100 pounds was effective and increased the dry weights harvested in May and June, but in subsequent harvests the effects from the nitrogen differentials were not significantly different. However, it does seem reasonable to feel (1) that the "A" treatment which received only 100 pounds of nitrogen did fall down in its yield of dry matter at both the 17½- and the 20½-month harvests, and (2) that the 220-pound nitrogen total on the "D" treatment did not produce the maximum yield of total dry matter at the maximum age harvested.

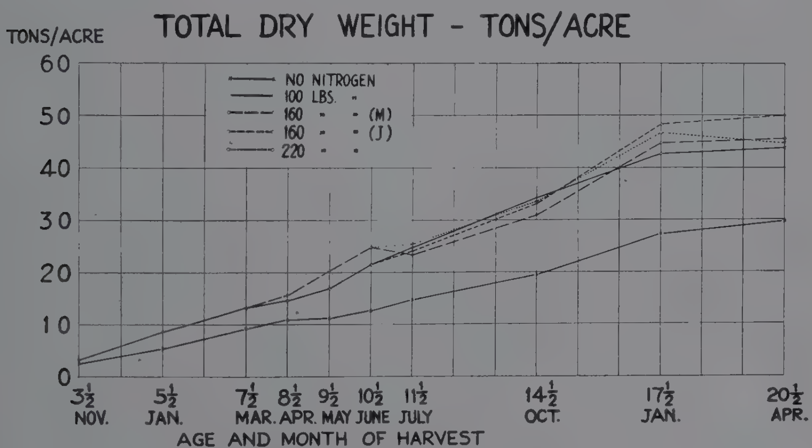

Fig. 6

5. On the Composition of the Total Dry Weight:

(a) Per cent Reducing Sugars (Fig. 7): Here we find a very clear-cut relationship, as the percentages of reducing sugars show a direct effect of the nitrogen that had been supplied; these treatment effects are highly significant at the last three preharvests.

Apparently the reducing sugars were generally high in the young cane during its first winter, then dropped sharply and remained lower throughout the first summer, regardless of the nitrogen fertilization. However, by October the nitrogen fertilizer had exerted its positive effects, and the reducing sugars were again quite high. After 14½ months there was a rapid decline which, except for the high nitrogen treatment (Treatment D), brought the percentage down below 2 per cent at the last preharvest.

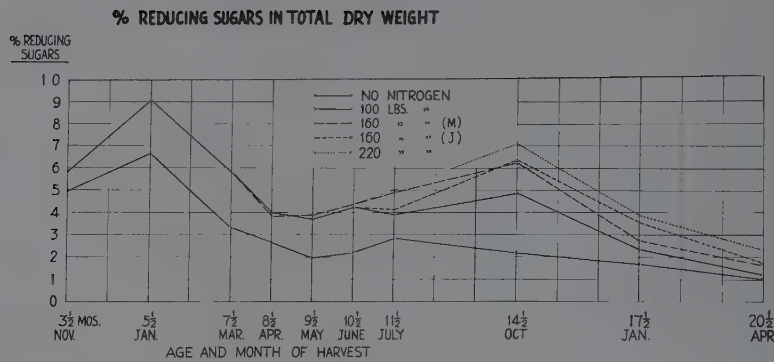

Fig. 7

(b) Per cent Sucrose (Fig. 8): This measurement, as expected, shows an inverse relation with the per cent reducing sugars. Effects of treatment although not statistically significant appear to be positive at 14½ and 17½ months, but are somewhat confused at 20½ months when they are all fairly close together, regardless of their respective nitrogen treatments.

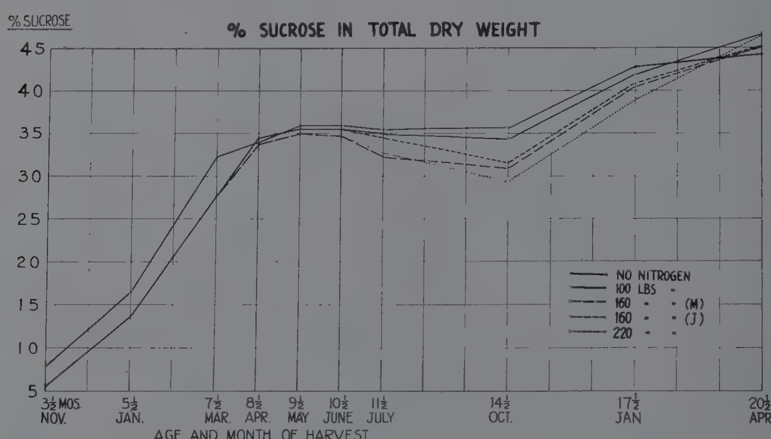

Fig. 8

A very rapid rise in per cent sucrose came during the first 7 or 8 months and then no further increase in concentration occurred until after the warm summer and fall seasons in which fast growth was taking place. There was a very considerable pickup in per cent sucrose again in January, and this, in spite of the fact that both total green and dry weights show parallel increases. Thus it is apparent that we can have an increase in cane and a corresponding and simultaneous increase in the per cent sucrose in this same cane. A further increase between January

and April was made while the yields of both green and dry weight were being checked by the drying-off procedure prior to the final field harvesting.

A very good idea of the inverse relationship between the per cent sucrose and per cent moisture is shown in Fig. 9. Here we see that the high nitrogen applica-

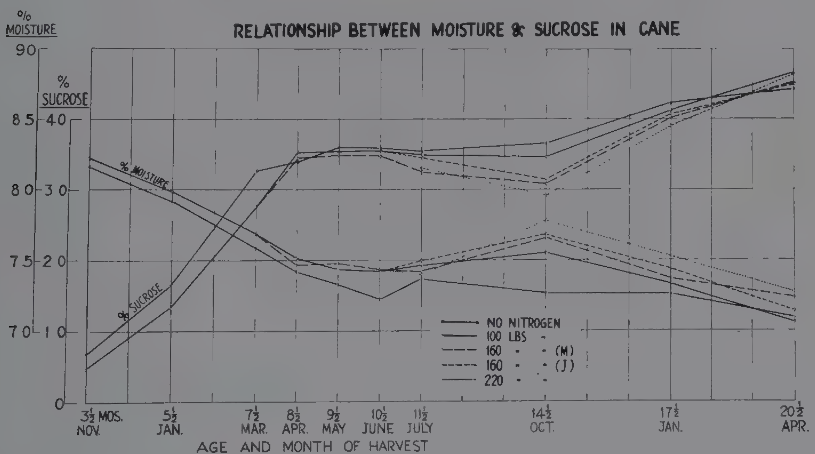

Fig. 9

tions have resulted in cane with high moisture and low sucrose whereas the smaller nitrogen supplies have given us cane with a lower moisture and higher sucrose content.

(c) Per cent Total Sugars (Fig. 10): This graph is naturally dominated by the per cent sucrose in the dry weight. It shows some influence of the nitrogen differentials, *i.e.,* lower percentages from the higher nitrogen applications, but there are

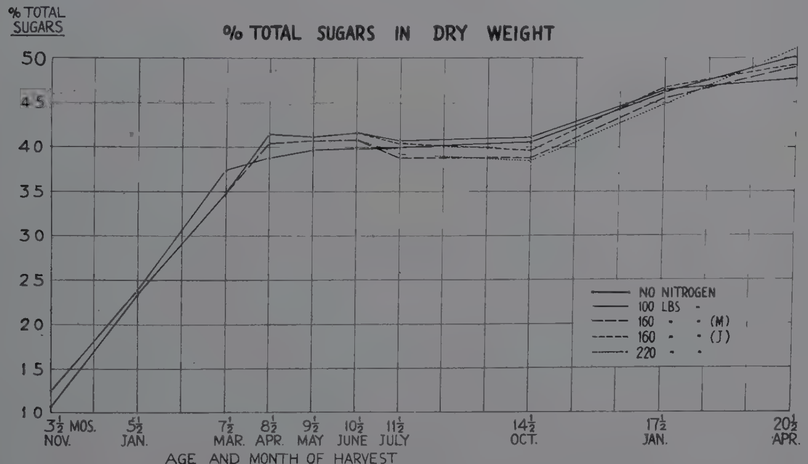

Fig. 10

some inconsistencies, so the effects are not clear. Although the experimental errors which are involved in these analyses were quite low, none of the treatment effects were found to be statistically significant. Perhaps factors other than nitrogen exert a greater influence on the percentage of total sugars; either age or season or both may play the major role. Worthy of note is the fact that regardless of treatment differences the percentage of total sugars, which had increased at a rapid rate prior to April, remained at the same level during the subsequent 6 months of higher temperatures and longer days.

(d) Per cent Nitrogen (Fig. 11): With but a single exception Fig. 11 shows that the nitrogen content of the total dry weight reflected the amounts of nitrogen applied. Statistically, the treatment effects are highly significant.

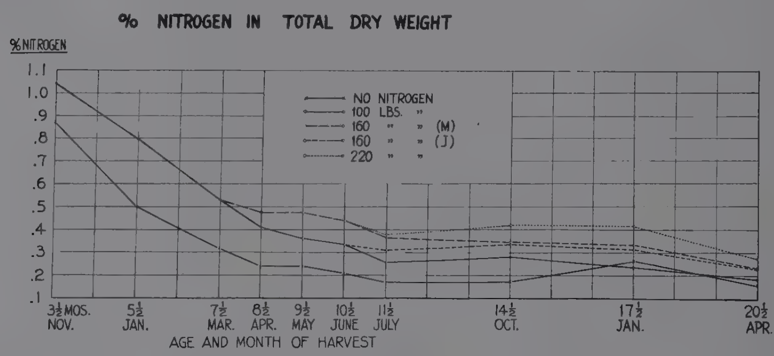

Fig. 11

In general the per cent N in the fertilized cane dropped from 1.0 to 0.5 per cent between 3½ and 8½ months; thereafter only a slight further reduction took place that was not the effect from the nitrogen applications.

At the age of 7½ months (in March), we found .53 per cent N in the total dry weight of the crop samples which had been fertilized with nitrogen at 100 pounds per acre. At 10½ months (in June), this figure had dropped to .33 per cent N when no additional nitrogen had been supplied in March. However, when another 60 pounds of nitrogen was given in March (Treatment C), a nitrogen percentage of .43 was found in the June samples. Furthermore, an application of 60 pounds per acre made in June to cane which had only received a total of 100 pounds per acre to date (Treatment B) was subsequently effective in holding the per cent N in the crop to a level quite comparable with Treatment "C". Since it was found that these two treatments—B and C—produced the optimum final sugar yields at 21½ months, it might be important to record here the following facts for future reference:

(1) At the age of 7½ months (in March), a crop which had already received

a total of 100 pounds of nitrogen some 4 months previous, and which showed only .53 per cent N in its total dry weight, responded favorably to an additional 60 pounds of nitrogen per acre (Treatment C).

(2) At the age of 10½ months (in June), a crop which had received 100 pounds of nitrogen 4 months previous, and which showed only .33 per cent N, responded favorably to an additional 60 pounds of nitrogen (Treatment B).

(3) At the age of 10½ months (in June), a crop which had then received a total of 160 pounds of nitrogen, and which showed .43 per cent N in its total dry weight (Treatment C), *did not respond* to an additional 60 pounds of nitrogen (Treatment D) when it was harvested at 21 months of age.

Although this difference found in June, between a percentage of .33 in Treatment "B" which showed an economic response to a subsequent 60-pound application of nitrogen, and .43 in Treatment "C" which did not show a profitable response to another 60 pounds in June, is quite small, there is no reason why it cannot be reliably identified as an actual difference if truly representative samples of the crop are adequately secured for the nitrogen analysis. (In our case 4 samples would have identified .33 per cent and .43 per cent N as significantly different amounts.)

(e) Per cent Phosphoric Acid (Fig. 12): The March application of ammonium sulphate to Treatment C appears to have resulted in a higher concentration of phos-

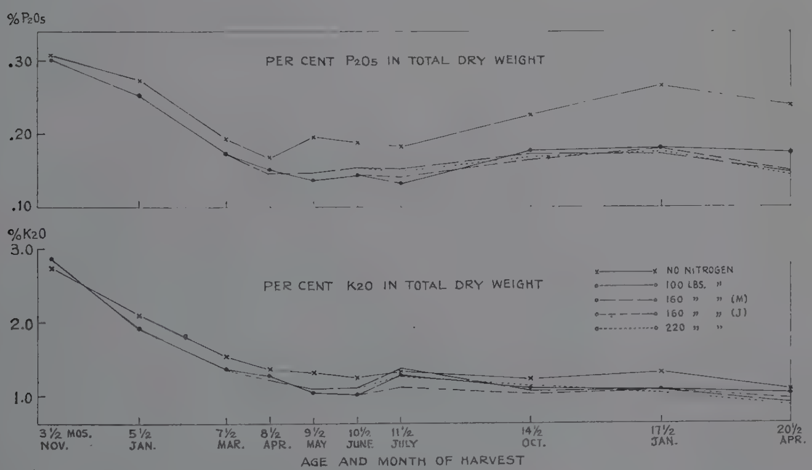

Fig. 12

phoric acid in the total dry weights harvested in May and June. This may have been an effect from the sulphate on the soil phosphate rather than from the nitrogen in this fertilizer. Thereafter, until the final preharvest, other differences

found in the percentages of P_2O_5 in the total dry weight of those crops which received nitrogen fertilizer were probably not the effects from the different nitrogen treatments. It is quite clear however, that the percentage of P_2O_5 in cane from the "no nitrogen" plots was consistently higher than that found in the nitrogen-fertilized cane, and at the final harvest, the low-nitrogen "A" plots also had cane with a higher concentration of phosphate than the more adequately nitrogen-fertilized plots. This is a quite commonly observed relationship between nitrogen and phosphate when the available supply of either one is actually deficient.

(f) Per cent Potash (Fig. 12): An effect from differences in applied nitrogen on the per cent K_2O in the total dry weight was not definitely established. There is a suggestion that the June applications of nitrogen to Treatments B and D, which stepped up the concentrations of nitrogen found thereafter, may have resulted in a slightly lower per cent K_2O in the crop harvested the following month, but, if so, this was only a temporary effect.

As was the case with per cent P_2O_5, the no nitrogen "X" plots also produced a crop with a higher percentage of K_2O than the nitrogen-fertilized crops.

The trends in the curves for per cent K_2O in dry weight of the preharvest samples are in general quite similar to those for both per cent N and per cent P_2O_5; apparently the concentrations of all 3 plant foods decrease rapidly during the first 10 months and thereafter remain fairly constant as long as the crop is kept growing normally.

(g) Total Nutrition and Nutrition Ratios: In Table I we have recorded data for future reference and hopeful interpretation. Plant physiologists have suggested that since chemical analyses of selected plant samples will indicate concentrations of the major nutrients in the crop, they can be used to guide fertilizer practices; ordinarily use is made of only a specific part of the crop, such as certain young leaves or stems for the plant sample to be analyzed. Since we had secured samples of the crop which included entire plants (except trash and roots), and as our gross analyses of these crop samples at the periodic harvests were sufficiently sensitive to reflect the different nitrogen treatments, these analyses ought to contain pertinent information if we can identify their relation with the final sugar yields harvested. Hence in Table I we have recorded for each treatment at each age harvested, the separate percentages of N, P_2O_5, and K_20 which were found in the total dry weight from the crop samples, and the sum total of these 3 percentage figures as the total nutrition. Then we have reduced these percentage figures to their respective milligram equivalents and calculated (*a*) the respective ratios of the N, P_2O_5, K_2O concentrations, and also (*b*) the ratio of $P_2O_5+K_2O$ to N. Since we had secured actual comparative yields of total dry weights, we are also able to present the total nutrition for each treatment in terms of total pounds of N, P_2O_5, and K_2O in the dry weight harvested, and to indicate the relative proportions of this total nutrition which were contributed by its three components. Unfortunately we fail to find sufficiently consistent relationships with the final sugar yields in these data to accept them at this time for reliable guidance in nitrogen fertilization of sugar cane crops.

TABLE I

NUTRIENT COMPOSITION OF TOTAL DRY WEIGHTS

Treatment	Age (mos.)	Lbs. N to date	Percentages in total dry weight N	P_2O_5	K_2O	Sum ($N+P_2O_5+K_2O$)	Ratio* $N\text{-}P_2O_5\text{-}K_2O$	$P_2O_5+K_2O \div N$	Pounds per acre in total dry weight Total lbs. N, P_2O_5, K_2O	Proport. (%) $N\text{-}P_2O_5\text{-}K_2O$
X	3½	0	.866	.307	2.755	3.928	46–10–44	1.16	160	22– 8–70%
A	3½	40	1.048	.304	2.869	4.221	50– 9–41	.99	215	25– 7–68%
X	5½	0	.503	.275	2.181	2.959	38–12–50	1.62	339	17– 9–74%
A	5½	100	.797	.254	1.923	2.974	52–10–38	.91	524	27– 9–64%
X	7½	0	.311	.191	1.568	2.070	35–13–52	1.87	383	15– 9–76%
A	7½	100	.534	.170	1.385	2.089	51–10–39	.96	555	26– 8–66%
X	8½	0	.244	.164	1.363	1.771	33–13–54	2.07	382	14– 9–77%
A	8½	100	.406	.148	1.238	1.792	47–10–43	1.13	533	23– 8–69%
C	8½	160	.475	.146	1.222	1.843	51–10–39	.95	576	26– 8–66%
X	9½	0	.243	.196	1.333	1.772	32–15–53	2.11	382	14–11–75%
A	9½	100	.358	.136	1.040	1.534	48–11–41	1.09	516	23– 9–68%
C	9½	160	.474	.145	1.080	1.699	54–10–36	.86	680	27– 9–64%
X	10½	0	.207	.185	1.222	1.614	30–16–54	2.29	425	13–11–76%
A	10½	100	.335	.141	1.081	1.557	45–11–44	1.21	675	21– 9–70%
C	10½	160	.431	.152	1.149	1.732	50–10–40	1.00	860	25– 9–66%
X	11½	0	.172	.180	1.340	1.692	25–16–59	2.94	493	10–11–79%
A	11½	100	.254	.130	1.330	1.714	35–11–54	1.86	848	15– 8–77%
B	11½	160	.309	.140	1.140	1.589	42–11–47	1.37	772	20– 8–72%
C	11½	160	.365	.150	1.360	1.875	43–10–47	1.36	866	20– 8–72%
D	11½	220	.372	.150	1.290	1.812	44–10–46	1.27	915	21– 8–71%
X	14½	0	.172	.223	1.206	1.601	26–20–54	2.86	708	11–14–75%
A	14½	100	.276	.174	1.113	1.563	39–14–47	1.58	1071	18–11–71%
B	14½	160	.341	.163	1.012	1.516	46–13–41	1.17	1009	22–11–67%
C	14½	160	.346	.171	1.064	1.581	45–13–42	1.21	974	22–11–67%
D	14½	220	.427	.167	1.160	1.754	49–11–40	1.04	1198	24–10–66%
X	17½	0	.251	.263	1.308	1.822	31–20–49	2.18	1018	14–14–72%
A	17½	100	.236	.178	1.072	1.486	36–16–48	1.80	1255	16–12–72%
B	17½	160	.314	.178	1.073	1.565	43–14–43	1.36	1498	20–11–69%
C	17½	160	.329	.173	1.071	1.573	44–14–42	1.28	1419	21–11–68%
D	17½	220	.413	.175	1.062	1.650	50–12–38	1.02	1551	25–11–64%
X	20½	0	.159	.239	1.205	1.603	24–21–55	3.15	959	10–15–75%
A	20½	100	.185	.171	1.056	1.412	31–17–52	2.25	1212	13–12–75%
B	20½	160	.231	.148	.959	1.338	38–15–47	1.62	1332	17–11–72%
C	20½	160	.234	.148	.924	1.306	39–15–46	1.55	1183	18–11–71%
D	20½	220	.274	.143	.847	1.264	45–14–41	1.23	1150	22–11–67%

* Based on chemical equivalents.

6. On the Composition of Leaves and Crusher Juices:

(a) Per cent Nitrogen in the Leaf-punch Samples (Fig. 13): Since we had rather hoped that this index of nitrogen from the active green leaves would be a useful guide to nitrogen fertilization, samples from the crops were taken more frequently for total nitrogen analyses. The results are best discussed after a study of Fig. 13.

There is no doubt that the leaf-punch analyses have reflected the different levels of nitrogen in the crop which resulted from the different nitrogen supplies made available. Nearly all of the differences resulting from the different nitrogen totals are statistically significant, and the effect of changing the nitrogen supply was identified from the leaf analyses within a month after each nitrogen application. This indicates both the rapidity with which applied nitrogen fertilizer gets into the crop,

and the reliability with which the leaf-punch nitrogen index identifies a changed nitrogen status.

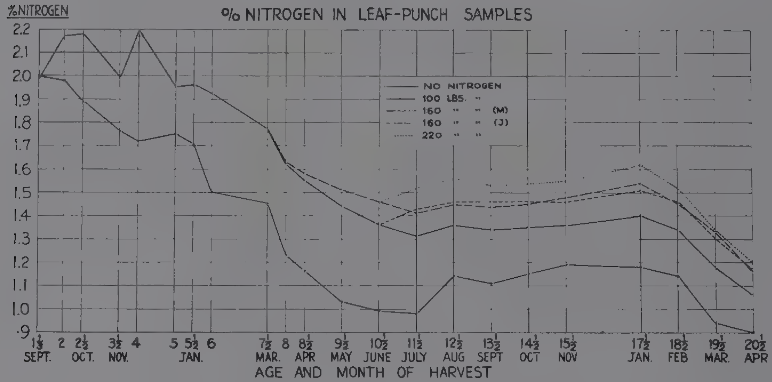

Fig. 13

The coefficients of variability for the leaf-punch nitrogen analyses were found to be quite low, seldom running over 5 per cent, and significant differences in per cent N of between 0.05 and 0.07 per cent were measured with 8 replicates of the leaf-punch samples. This indicates a very low variability in the specific leaf material analyzed and also a low analytical error. Thus the method or procedure which has been laid down by Yuen and Hance (6) for studying the nitrogen in specific cane leaves is believed to be highly reliable, but the interpretation of its results is another matter.

The percentage of nitrogen found in these leaves up to the time the crop was 5½ months old was fairly close to the 2.0 per cent level which has been suggested as an adequate nitrogen level for samples from active cane leaves under 6 months of age. The drop to about 1.75 per cent at 7½ months in March seemed to be a normal decrease. Thereafter the "A" plots continued to drop and at 10½ months were below the 1.5 per cent N level at which it seemed desirable to keep the per cent N in cane leaves until the crop was one year old. Even the additional 60 pounds of nitrogen applied in March failed to stop the decline, although it did slow it up somewhat. An unexpected "status quo" was experienced by all treatments between June and October, and the continued decline in nitrogen was stopped whether or not the cane had received more nitrogen fertilizer in June, so the levels at 17½ to 18 months were somewhat higher than believed desirable. This must have been due to a late contribution of nitrogen made by the soil; perhaps we saw a suggestion of this effect in the monthly soil analyses (Fig. 2). After October when the crop was 17½ months old, a further decline in the per cent N of the leaf-punch samples was quite abrupt and at the last preharvest, none of the treatments were above 1.2 per cent; this indicated that their nitrogen supplies had all been fairly well used up.

But to return to our chief interest in Fig. 13 which is to determine whether the leaf-punch nitrogen data could have been used to tell us in March or in June that

the crop to be harvested a year hence would or would not need more than the basic 100 pounds of nitrogen which it had already received.

In March when we found 1.77 per cent N in the leaf samples, we had apparently an inadequate supply indicated for a 21-month crop, as Treatment A which received no more nitrogen eventually proved less productive of commercial sugar than Treatment C which received 60 pounds more nitrogen in March.

In June at 10½ months, the leaves from Treatment A showed only 1.36 per cent N. Apparently this was also too low because when 60 pounds more nitrogen were applied to make Treatment B, the ultimate gain in sugar was highly significant and profitable. However, Treatment C which had already received 160 pounds of nitrogen before June and which now showed a leaf-nitrogen percentage of 1.46 apparently had enough nitrogen, for an additional nitrogen fertilization then did not result in any final increase in sugar. From this it would appear that a nitrogen index from leaf-punch samples of 1.36 per cent at 10½ months in June represented an inadequate nitrogen composition, but that an index of 1.46 per cent was quite adequate for the 21-month crop of 32–8560 cane. This difference between 1.36 and 1.46 is a very small one, and even though it can be measured as significant, we hesitate to suggest these narrow limits for guidance in nitrogen fertilization until considerably more verification of these data is obtained, because that levelling off of the per cent nitrogen in the leaves between June and October may or may not always occur.

Reference to Fig. 13 does show a very clear-cut difference between the crop which received no nitrogen fertilizer (Treatment X) and the treatments which received nitrogen. Hence there is little doubt but that the nitrogen indices from the "X" plots, which were relatively low after the second month and definitely low at 7½ months, indicated a need for more nitrogen, but this same indication could be observed in the easily visible leaf symptoms also. Furthermore after the crop has already been given a fair amount of nitrogen, it is apparently not going to be as easy to interprete this same nitrogen index for guidance of additional nitrogen needs—and this is the specific guidance we need.

(*b*) *Other Foliar Indices* (*Fig. 14*): Clements (1) has suggested the use of certain foliar indices to show the kind of cane growth which is being made, with the thought that certain corrective measures can be applied to change the type of growth, if it is undesirable. As a supplementary study, we were able to secure measures of the suggested primary and secondary indices from 3 "X" plots but from only 2 plots each from Treatments A, B, C, and D. For ready reference the results from the analyses made on blades and sheaths of the active green-leaf samples are shown graphically in Fig. 14.

Our chief interest in these data is centered on the leaf analyses which were made from the April-May-June samples, since 3 nitrogen differentials were then in effect; furthermore, corrective measures, if needed, would have to be applied at about this time. The picture is none too clear, so perhaps we are justified in averaging the data from these 3 preharvests. When this is done we have the following averages to reconcile with their associated final field yields:

Plots	No. of plots sampled	Pounds N applied to date	Averages from April-May-June harvests: % total sugars in sheaths	% dry matter in sheaths	% total nitrogen in blades		Final field yield averages: TCA	Y%C	TSA
X	3	0	10.403	29.2	.666	(X)	72	14.0	10.9
A & B	4	100	10.614	27.0	.873	(A)	103	14.0	14.4
						(B)	121	12.9	15.5
C & D	4	160	11.841	27.2	.970	(C)	117	13.2	15.3
						(D)	121	13.0	15.5

Considering first the suggested primary index, *i.e.*, the percentage of total sugars in the dry weight of the young leaf sheaths, we note practically no difference

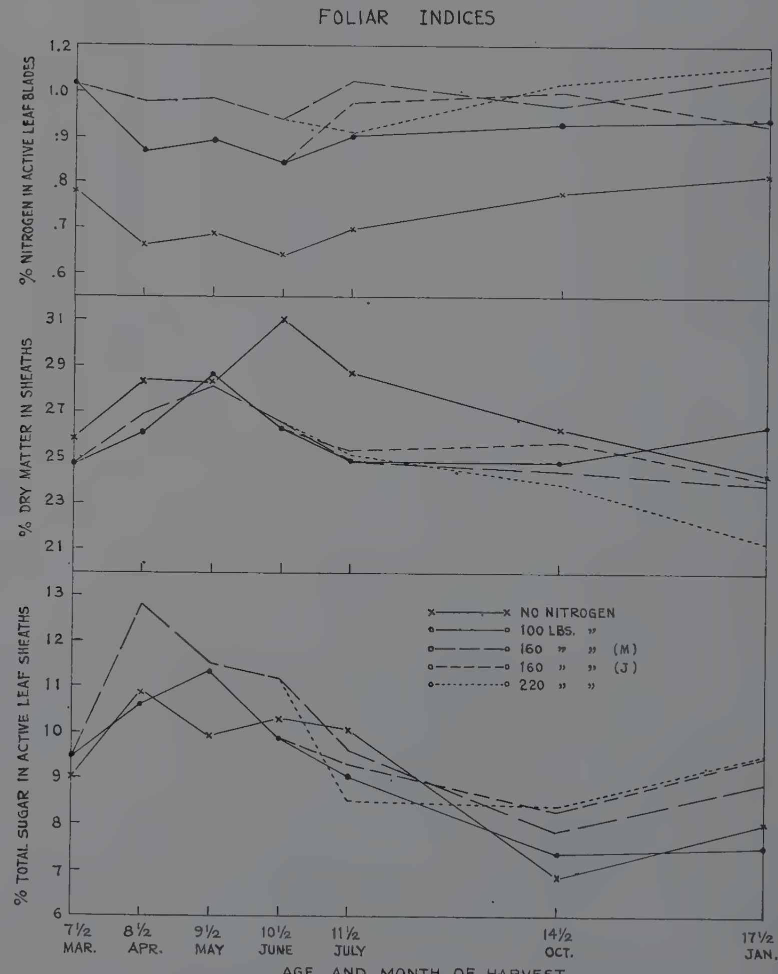

Fig. 14

between the "X" and the "A and B" plots, but a slightly higher sugar index from the "C and D" plots. Since we actually harvested more cane and sugar from both the A and B than from the X plots, it is difficult to see any relation between this primary index and the final yields which were harvested from the specific plots the leaf samples were taken from. Furthermore, although the leaf sheaths from the C and D plots at this time carried a higher concentration of total sugars than the A and B plots, the final cane and also sugar yields were higher from the C than from the A plots, so apparently the higher carbohydrate status of these leaf sheaths was not due to a slower growth of the cane. As a matter of fact the per cent total sugars in sheaths from Treatment C was higher than from Treatment A in every sample analyzed.

Although a ratio of 12 to 1 was found for per cent total sugars in sheaths to per cent total nitrogen in blades for both the A and B and the C and D plots, apparently the 10.6 per cent sugars and .87 per cent nitrogen for the A and B plots were not indicative of a satisfactory carbohydrate or nitrogen status at this stage, for an additional 60-pound application of nitrogen immediately thereafter made Treatment B better than Treatment A. On the other hand, when 11.8 per cent sugars and .97 per cent nitrogen were found, a similar 60-pound application of nitrogen did not make Treatment D any better than C.

Using the 40 samples collected at the March, April, May, June, July harvests, we find several correlations which should be recorded here for future reference. The following correlation coefficients were obtained:

(*a*) Between % N in green-leaf blades and in sheaths of same leaves.... $r = +.71 \mp .08$†

(*b*) Between % dry weight in leaf sheaths and % total sugars in same sheaths .... $r = -.38 \mp .14$*

(*c*) Between % moisture in leaf sheaths and % N in leaf blades from duplicate samples .... $r = +.15 \mp .15$

(*d*) Between % N in leaf blades and per cent total sugars in leaf sheaths from duplicate samples .... $r = +.03 \mp .16$

(*e*) Between % N in leaf blades and per cent N in total dry weight from duplicate samples .... $r = +.06 \mp .16$

(*f*) Between % total sugars in leaf sheaths and per cent total sugars in total dry weight from duplicate samples.... $r = +.33 \mp .14$*

* Significant. † Highly significant.

Apparently we shall need further study of these specific foliar indices before we can hope to be guided by them in our adjustment of nitrogen fertilization. The extent of the variation in the percentage of total sugars found in the leaf sheaths, as indicated below, from separate replicated plot samples, makes it appear that this measurement is subject to some rather wide fluctuations; this can make its interpretation very difficult.

EXTENT OF VARIATION IN PER CENT TOTAL SUGARS IN LEAF SHEATHS OF CANE FROM REPLICATED PLOTS

Plot No.	From plots which had received 100 pounds N/acre — Sampled in — March	April	May	June	Plot No.	From plots which had received 160 pounds N/acre — Sampled in — April	May	June
23	8.32	9.69	7.76	8.44	24	14.07	9.31	10.56
28	8.62	9.60	12.42	10.25	29	11.11	11.51	8.85
34	9.06	11.19	12.92	10.97	33	14.67	13.86	13.70
37	10.32	12.12	12.47	9.53	36	11.30	11.37	11.79
24	8.87							
29	9.54							
33	11.29							
36	9.98							

(*c*) *Per cent Nitrogen in the Crusher Juices (Fig. 15):* This is one of the clearest pictures we obtained; the effect from nitrogen applied to the cane upon the nitrogen found in its crusher juice only one month after application is positive, and is measured with high statistical significance at each preharvest. From the curves in Fig. 15, tentative criteria for nitrogen deficiency or nitrogen sufficiency can be

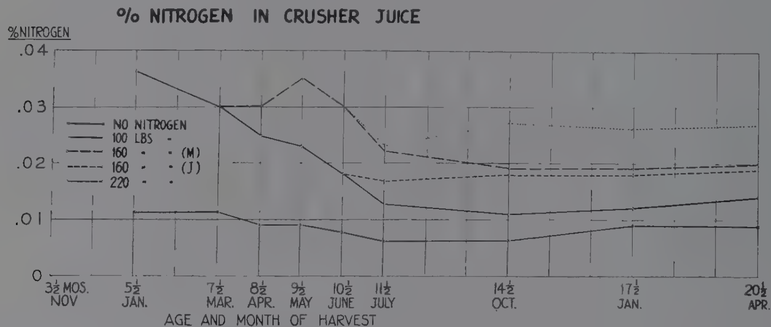

Fig. 15

recorded for further verification. For instance, at 7½ months .030 per cent nitrogen in the crusher juice was too low and a better sugar yield was finally secured when an additional 60-pound application of nitrogen held this level at or above .030 per cent until 10½ months. But at 10½ months, a figure of .030 per cent was an index of an adequate amount of nitrogen for the remainder of the 21-month crop, for no gain in sugar was secured when another 60 pounds of nitrogen were supplied in June. However, the figure of .018 per cent nitrogen in juice at 10½ months was apparently too low, and an extra 60 pounds of nitrogen were needed to keep this figure from still further decline during the rest of the 21-month crop period, and to thereby enable Treatment B to produce more sugar than Treatment A.

So, as was the case with per cent nitrogen in the leaf-punch samples, and per cent nitrogen in total dry weight, before we can use the composition of nitrogen in crusher juices as a guide for further nitrogen needs, we must obtain many more related measurements concerned with plant nitrogen analyses and their associated final sugar yields.

(*d*) *On the per cent Chlorophyll in the Green Leaves (Fig. 16):* Leaf color has always been used by our planters as a qualitative index of the nitrogen status of their crop. Since this color is dominated by the chlorophyll in the leaves, a numerical measure of the chlorophyll content should be a more exact piece of information than a personally influenced descriptive color term.

From Fig. 16 it will be noted that the per cent chlorophyll of the "X" plots at the first preharvest was lower than that of the fertilized cane, although our observations at 3½ months had not revealed any significant color difference; after this age however, this color difference was easily seen.

In general the chlorophyll content of the leaves was increased with each application of nitrogen. All treatments showed the expected seasonal influences, being high in the winter months and low during the longer sunny days of summer. The

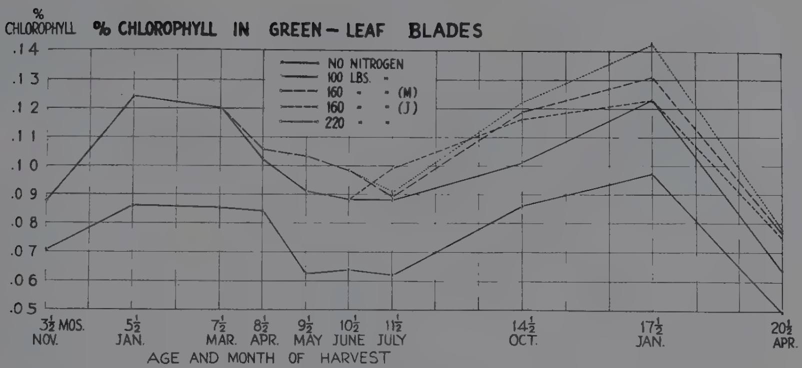

Fig. 16

rapid falling off at the end of the crop was undoubtedly due to the effects of the "drying-off" period.

Like other percentage data which were recorded, it is still too early to attempt an interpretation of the differences in the percentage of chlorophyll that were found between 7½ and 10½ months.

7. *On the Yields Per Acre:*

All data concerned with yields per acre are subject to the high experimental error associated with the harvesting of small unit plots of field-grown sugar cane. Thus although the block variance was identified and separated from the error variance, the residual or experimental error is still high. In the April, May, and June preharvests, 16 replicates of two different nitrogen treatments, *i.e.,* 100 and 160 pounds per acre were available for average yields; in the last 4 preharvests 8 replicates of the 4 nitrogen totals were available. In spite of these numbers, few of the measured yield differences are proved effects of treatments and so their interpretation must not be considered final.

(*a*) *Reducing Sugars, Sucrose, and Total Sugars:* Following the application of the first nitrogen differential in the March fertilization, we find increases in tons per acre of both reducing sugars and sucrose from the crop which had received a total of 160 pounds of nitrogen; this resulted in significant increases in total sugars in the May and June preharvests of 1.19 and 1.15 tons, respectively, over the crop which had received only 100 pounds of nitrogen.

After the June application when the differential amounts of nitrogen became effective, an interesting story of the effects of nitrogen upon sugar accumulation by a cane crop is unfolded. Each application and increase in nitrogen produced an increase in tons of reducing sugars. The 60-pound nitrogen application in June produced more reducing sugars in the preharvests at 14½, 17½, and 20½ months than the comparable nitrogen application that was made earlier—in March. On the other hand the yields of sucrose and total sugars per acre appear to have been affected somewhat differently. At 11½ and 14½ months, Treatment "A" which had received only 100 pounds of nitrogen had produced as much or more sucrose and total sugars per acre as plots which had received more than 100 pounds of

nitrogen. At 17½ months, Treatment "A" had fallen below Treatment "B" (160 pounds N) which then assumed the lead and held it again at 20½ months; and Treatment "C" which had its last 60 pounds of nitrogen in March was never quite able to catch Treatment "B" (last 60 pounds in June) in its yields of sucrose or total sugars.

Very little difference in total sucrose and in total sugars per acre was measured at 17½ or at 20½ months between crops which received 100 pounds nitrogen, 160 pounds nitrogen early, or 220 pounds nitrogen per acre. These assumptions are made from the data in Table II.

TABLE II
SUGARS IN TOTAL DRY WEIGHT—TONS PER ACRE

Treatment	Total lbs. N applied by June	Last 60 lbs. N applied	July harvest—11½ mos. Tons per acre: Reducing sugar	Sucrose	Total sugars	October harvest—14½ mos. Tons per acre: Reducing sugar	Sucrose	Total sugars
A	100	November	.95	8.68	10.09	1.69	11.78	14.08
B	160	June	1.00	8.44	9.88	2.06	10.59	13.21
C	160	March	1.16	7.58	9.13	1.90	9.58	11.97
D	220	June	1.27	8.33	10.03	2.45	9.92	12.90

Treatment	January harvest—17½ mos. Tons per acre: Reducing sugar	Sucrose	Total sugars	April harvest—20½ mos. Tons per acre: Reducing sugar	Sucrose	Total sugars
A	1.03	17.54	19.49	.53	20.41	22.01
B	1.63	19.68	22.34	.82	22.57	24.59
C	1.22	18.14	20.31	.75	20.70	22.52
D	1.76	18.26	20.98	1.03	20.64	22.76

(*b*) *Millable Cane and Recoverable Sugar (Fig. 17):* Our chief interest in these data lies in the last 4 harvests, since our plantations have been known to take off crops which have approximated the ages that are represented by these later harvests. It is in these data that we have the real "pay-off" for the planter, and what a changing picture it is!

It should be recorded here that all of the preharvest yields have been reported on their actual *net* area basis of 25 square feet per plot, and hence they should and will be found approximately 24 per cent higher than they would be if calculated on their gross area basis. This can be seen from the following reconciliation between the cane yields as reported for the April preharvest at 20½ months and the actual final field yields of cane which were obtained within the next 3 to 5 weeks and which were reported on a gross area basis:

Treatment	Last preharvest sample TCA (net area)	Final field yield TCA (gross area)	Per cent difference
A	136.3	110.9	+22.9
B	158.0	120.0	+31.7
C	151.2	120.2	+25.8
D	149.6	122.7	+21.9
X	91.2	71.8	+27.0
		Average	+25.8

At the age of 11½ months the optimum yield of recoverable sugar was obtained from the crop which had received only 100 pounds of nitrogen per acre, and this shows a very profitable increase over zero nitrogen. There was very little difference in the cane yields between the 4 treatments which had received nitrogen, even

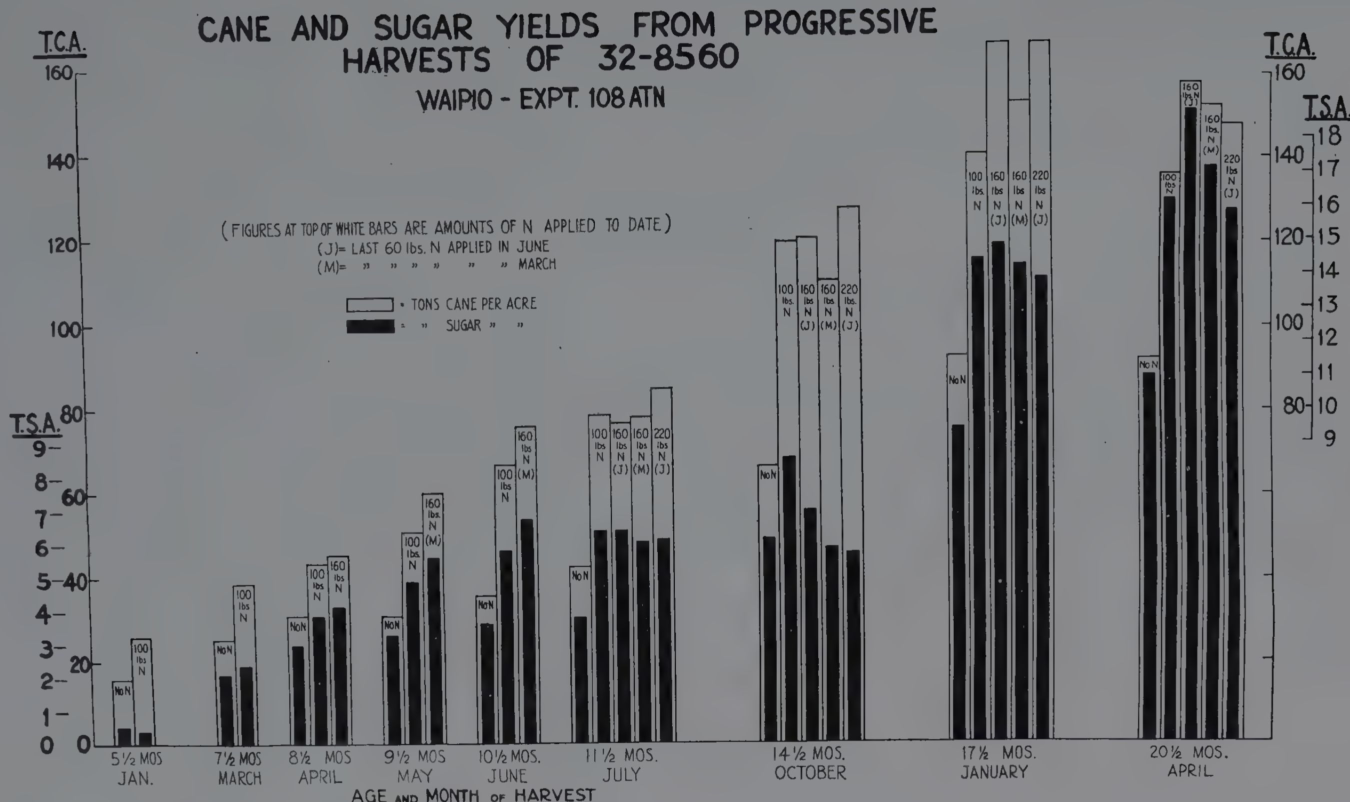
CANE AND SUGAR YIELDS FROM PROGRESSIVE HARVESTS OF 32-8560
WAIPIO - EXPT. 108 ATN
(FIGURES AT TOP OF WHITE BARS ARE AMOUNTS OF N APPLIED TO DATE)
(J)= LAST 60 lbs. N APPLIED IN JUNE
(M)= " " " " " " MARCH
= TONS CANE PER ACRE
= " SUGAR " "
T.C.A.
T.S.A.
5½ MOS JAN.
7½ MOS MARCH
8½ MOS APRIL
9½ MOS MAY
10½ MOS. JUNE
11½ MOS. JULY
14½ MOS. OCTOBER
17½ MOS. JANUARY
20½ MOS. APRIL
AGE AND MONTH OF HARVEST

Fig. 17

though treatments "C" and "D" had been given 60 pounds more nitrogen than "A" and "B" some 4 months previous.

At 14½ months we find the best yield of recoverable sugar from Treatment "A" which had only received a total of 100 pounds of nitrogen. Again, no significant differences were measured in the cane yields between the 4 nitrogen-fertilized groups. Hence, it is assumed, and later will be shown, that the differences in cane quality have been influenced by the nitrogen applications and thus are responsible for these sugar yields. It might appear that the zero nitrogen (X) plots have produced more sugar at this harvest than the higher nitrogen (D) plots, but this assumption can be challenged since it must be remembered that there were only 3 replicates of these "X" plots, and the experimental error at this October harvest was exceptionally high.

We find great increases in sugar yields from all treatments between 14½ and 17½ months, but Treatment "A" from its 100 pounds of nitrogen still appears to be the most profitable for this 32–8560 cane crop at Waipio, for there was apparently more cane tonnage to handle from the higher nitrogen treatments and no greater sugar yield recovered therefrom.

Finally, at the age of 20½ months, although we identified no differential nitrogen effects as statistically significant, there appears to have been less cane harvested from the 100-pound treatment than from those crops which received extra nitrogen, but at the same time it does not appear that Treatment "D" which had received 220 pounds of nitrogen had produced any more millable cane at 20½ months than plots which had been given only 160 pounds. As far as the recoverable sugar yields were concerned, those from the 220-pound nitrogen application, because of a poorer cane quality, were still under the yields obtained from the 100-pound application, but at the same time this 100-pound application for cane harvested at 20½ months was apparently inadequate since its sugar yield was less than that from the 160-pound applications.

These yield data, when set up as in Table III to show the increases or decreases made during specific growth periods, provide some interesting information and show the comparative effects of the differential nitrogen treatments.

TABLE III

AVERAGE* INCREASES OR DECREASES IN YIELDS OF TCA AND TSA

			TCA (net area)				
Growth period	Months	Age of crop (mos.)	X	A	B	C	D
1	Aug.–Jan.	0– 5½	+15.9	+22.9	+24.9	+26.5	+28.9
2	Jan.–Apr.	5½– 8½	+15.3	+19.0	+21.3	+18.7	+18.8
3	Apr.–July	8½–11½	+11.8	+38.0	+30.9	+32.4	+37.7
4	July-Oct.	11½–14½	+24.6	+39.8	+44.0	+33.6	+43.3
5	Oct.-Jan.	14½–17½	+24.4	+20.5	+45.1	+41.2	+37.3
6	Jan.–Apr.	17½–20½	— .8	— 3.9	— 8.3	— 1.2	—16.5
			TSA (net area)				
			X	A	B	C	D
		1.....	+ .51	+ .21	+ .21	+ .24	+ .32
		2.....	+2.50	+3.48	+3.95	+4.02	+3.96
		3.....	+ .80	+2.77	+2.33	+1.77	+1.91
		4.....	+2.41	+2.19	+ .53	— .10	— .40
		5.....	+3.19	+5.76	+7.78	+8.31	+8.04
		6.....	+1.66	+1.82	+4.05	+2.88	+2.02

* Average from 8 plots of Treatments A, B, C, and D, and from 3 plots of Treatment X.
Note: The horizontal bar (____) in the columns indicates that a nitrogen fertilizer application was made during the previous growth period.

During the first 2 growth periods, while all 32 fertilized plots were similarly enjoying the effect from 100 pounds of nitrogen, the recorded increases in tons cane per acre and tons sugar per acre were quite similar; such differences as are noted being only the chance effects from field variation.

The March applications of nitrogen to the C and D plots, which did not increase the cane yields over the A and B plots in the third and possibly the fourth growth-period, apparently did result in less recoverable sugar being stored up.

The effect on Treatment B from the June nitrogen application was an increase in cane tonnage over the previous period and also a sharp decline in the amount of sugar stored during the fourth period. A similar trend was found in the cane and sugar yields from Treatment D's nitrogen application in June.

The rather remarkable increases in the sugar yields during the fifth growth period when the crop was 14½ to 17½ months old are worthy of note and should be a warning to anyone who would "short crop" this cane variety. All treatments made their best accumulation of recoverable sugar during this 3-month growth stage—averages of 1.9, 2.6, 2.8, and 2.7 tons per acre per month being recorded for Treatments A, B, C, and D, respectively. Furthermore, it should be emphasized again that these increases were made simultaneously with increases in cane yields which, except for Treatment A, were not significantly less than gains made in previous growth periods.

During the sixth growth period the beneficial effects of the general practice of "drying-off" irrigated cane crops before harvesting are quite nicely verified. The last round of irrigation was given on January 21 and thereafter until the final harvest only 5.2 inches of rainfall were received. Apparently, cane growth was checked, moisture was lost from the crop, and green leaves were prematurely added to the trash. Certainly the net result was less cane tonnage to be harvested. Though not statistically significant, Treatment D, the high nitrogen treatment, appeared to take the greatest setback and lose more cane weight than lower nitrogen treatments; and Treatment B which was fertilized in June may have dropped off more than the "C" plots which were fertilized in March. At the same time all plots made increases in recoverable sugar, with the best gains being made by Treatments B and C; even the zero nitrogen "X" plots continued to store up sugar during this period at better than one-half ton per acre per month!

For those who like to compare relative performance or yields from cane lands on the basis of tons sugar-per-acre-per-month (TSAM) we have prepared Table IV. Certainly, until the age of 17½ months, Treatment A which had received only 100 pounds of nitrogen had made a creditable performance; and it would seem that the results from the 220-pound nitrogen application had not been as good as from lesser amounts for a crop which was harvested at 20½ months. What the result might have been if there had been harvests at more advanced ages is purely speculative.

TABLE IV

Treatment	Total lbs. N applied by June	Last 60-lbs. N applied	Tons sugar-per-acre-per-month (net area) July at 11½ mos.	October at 14½ mos.	January at 17½ mos.	April at 20½ mos.
A	100	November	.56	.60	.82	.79
B	160	June	.56	.48	.85	.92
C	160	March	.52	.41	.81	.84
D	220	June	.54	.40	.79	.77

(*c*) *Relation Between Recoverable Sugar and Total Sucrose (Fig. 18):* In the sugar business there is no advantage in having the crop store up a lot of sucrose which cannot be commercially recovered, and so we are interested in the effect of nitrogen fertilizer on the amounts of total sucrose which are recoverable. Several

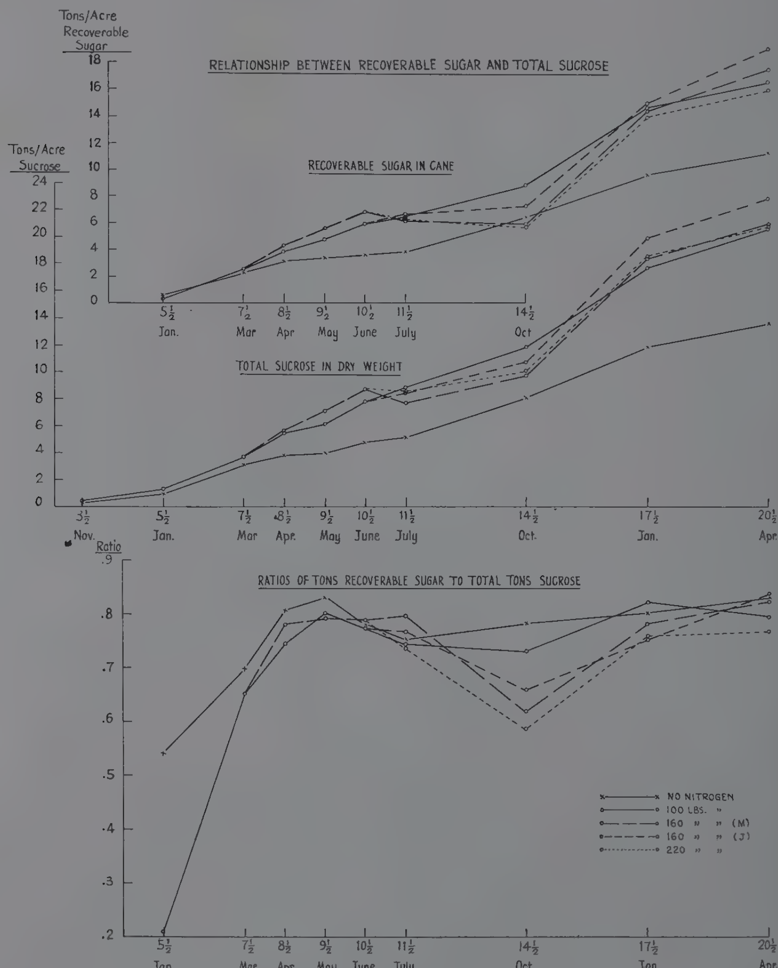

Fig. 18

separate references have already been made to these measurements but in Fig. 18 they are brought together to show better their relationships. Thus we see that although the total sucrose increased between July and October in all treatments, the recoverable sugars in the higher nitrogen treatments did not keep pace with them during the season of maximum temperatures and sunshine, and there was a

slight carry-over of these divergent responses to January. At other seasons the ratios of recoverable sugars to total sucrose were more nearly parallel.

Perhaps these recovery figures indicate that the so-called "harmful" effect from too much nitrogen is especially an effect on the percentage of total sucrose stored in the crop which cannot be commercially recovered at harvest. If this is so, then it gives emphasis to our earlier contention that our guidance for more intelligent nitrogen fertilization must be such as to enable us to avoid the application of an excessive amount of this nutrient.

8. On Cane Quality (Fig. 19):

Cane quality in this study has been recorded as "yield per cent cane" or Y%C, this term being used to indicate the unit yield of recoverable commercial sugar per

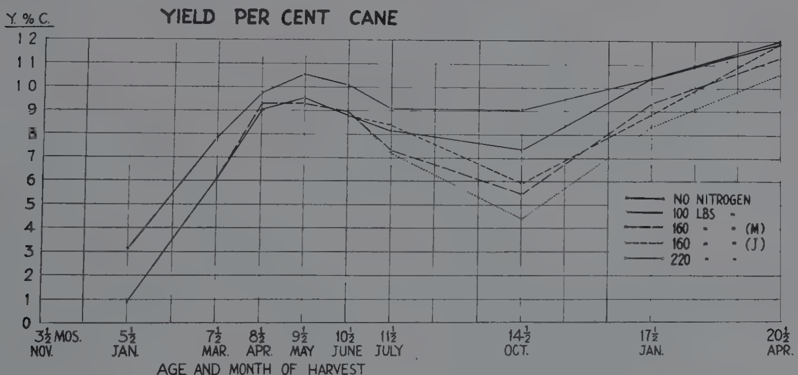

Fig. 19

100 units of cane milled. Basic data for this calculation came from the corrected* Brix and pol analyses of Waipio mill crusher juices from one half of the entire sample of millable canes harvested from each plot.

The effect of the nitrogen differentials upon the yield per cent cane is quite clear and consistent, and we find fewer pounds of recoverable sugar per 100 pounds of cane to have resulted from each increase in the total nitrogen applications.

There was especially low Y%C in October from the plots which had received over 100 pounds of nitrogen, but an excellent "comeback" in January indicates that an October harvest at 14½ months would have been a serious mistake.

A special attempt was made to find the reason for the poor cane quality from the October samples. Since the effect was greatest on Treatment D, a new collection of cane samples was made from a series of "D" plots in October. These were separated into 2 easily distinguishable groups: (1) primary and secondary stalks which had originated in 1940, and (2) suckers with at least 6 feet of stalk which had originated early in 1941. This second group was found by actual count to make up 31 per cent of the total number of millable stalks, and 20 per cent of

* Waipio Cuban A mill samples corrected to equivalents for Oahu Sugar Co.'s mill crusher juices.

the total weight of millable cane came therefrom. Crusher juice analyses from the 2 groups showed an average Y%C of 6.5 from the older stalks and of 4.7 from the millable sections of the sucker growth. A follow-up on this special study, made from the same series of plots in February, showed that millable suckers then made up 28 per cent of the total number and again 20 per cent of the total weight, but that the Y%C figures were now nearly equal, *i.e.,* at 9.8 for the older stalks and 9.7 for the suckers. Thus it is apparent that there is an optimum time to harvest a cane crop which has a stalk population with 28 to 30 per cent suckers carrying millable cane to the mill.

*9. On the Recovery of Plant Nutrients in the Total Dry Weight**:

Due to obvious practical difficulties in separating and collecting the trash and roots from each sampling station, we do not have as complete a picture of the nutrient recovery as we would wish; hence our figures are low. Both trash and roots make up quite a considerable amount of the total dry matter produced by a sugar cane crop. Calculations made by Moir (4) from work of Stewart and Wolters show the following approximate proportions of the various plant parts from H 109 cane grown at Waipahu:

AVERAGE MAKE-UP OF TOTAL DRY WEIGHT PRODUCED

Age	Top	Trash	Roots	Stalks
12 mos.	15%	14%	5%	66%
17 mos.	10%	17%	4%	69%
24 mos.	5%	24%	2%	69%

From data reported by Stewart (5) in which H 109 trash, tops, and stalks (but no roots) were weighed and analyzed, we have calculated that 15 per cent of the total nitrogen taken up by the plants (exclusive of roots) was found in the trash at 12 months, 22 per cent at 17 months, and 33 per cent at 24 months. From similar data secured from Waipio Experiment E at 12, 18, and 21 months, we note that 19 per cent, 28 per cent, and 25 per cent of the total nitrogen was found in the trash.

Pot studies (Project A 105—No. 161) of 4 cane varieties harvested at 12 months have shown the following percentages of total nitrogen recovered which were found in the roots only: 24 per cent from 31–1389, 28 per cent from H 109, 29 per cent from 32–1063, and 30 per cent from 32–8560. Unfortunately trash was not kept separate from tops for chemical analyses made in this study, but we have these percentages of the total nitrogen recovered which were found in the combined trash and tops at 12 months: 44 per cent from 32–8560, 48 per cent from 32–1063, 48 per cent from 31–1389, and 49 per cent from H 109.

These scattered data should tend to support our contention that our figures for nutrient recovery must be considered lower than the actual total uptake by the crop.

(*a*) *Nitrogen (Fig. 20):* In spite of the fact that our nitrogen recovery figures are incomplete, since they do not include the nitrogen in the trash or roots, they do provide us with a reliable indication of relative effects from the different nitrogen treatments, for statistically significant effects of treatment were found at each pre-harvest after the different amounts of nitrogen had been applied.

Of special interest is the fact that the crop grown without nitrogen fertilization

* Except trash and roots.

on the "X" plots was able to pick up between 50 and 60 pounds of nitrogen per acre during its first year of growth, and that an additional amount was secured during its second year. This must have been a contribution from the natural supply in

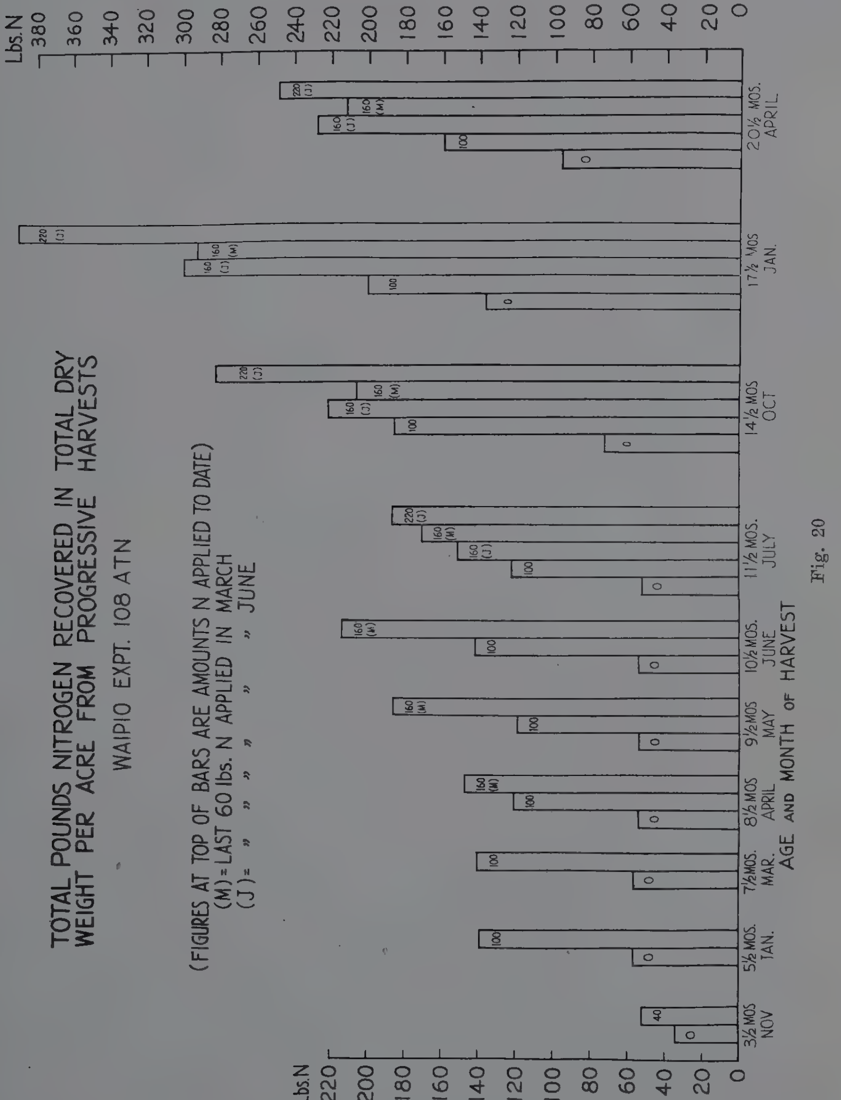

Fig. 20

the soil, and this is enlightening since the total nitrogen in the Waipio soil is relatively low.

At the age of 3½ months, the fertilized cane had been able to pick up only 55 pounds of nitrogen per acre—only 20 pounds more than the crop which received

no nitrogen, and reference to our observational notes and data shows that neither visible nor significantly measurable differences were noted at this time between the fertilized and non-fertilized plots. However, during the next 2 months when marked differences became apparent—and these were winter months too, the fertilized crop made a fairly complete absorption of the nitrogen which had been applied.

Definite uptake of the 60-pound nitrogen application made in March is seen in its efficient recovery in May and June.

The recovery figures for July are "out of line"; the reason is only speculative but it may be tied up with losses of nitrogen contained in the trash which was abundant at this harvest. Hence the recovery in the October samples and again in the January samples best reflects the nitrogen fertilizer effects after the June applications, and in both of these instances we must recognize the amount contributed by the soil, as indicated in the recovery by the zero nitrogen plots.

At the final preharvest in April, all treatments had lost nitrogen. Again the reason is believed to be associated with the trash losses, and in this case, because the crop was being artificially dried-off, many immature leaves which had not completed their normal life cycle and translocated their surplus nitrogen were dropped to the trash blanket and so their nitrogen was not found in the cane samples. This loss of nitrogen during the last 3 months was (1) greatest from the cane in Treatment D which had received the high total nitrogen application, (2) least from Treatments X (no nitrogen) and A (100 pounds nitrogen), and (3) intermediate from those plots which received the 160-pound applications.

(*b*) *Phosphate and Potash (Fig. 21):* The actual recoveries of phosphate and potash per acre of crop harvested are shown in Fig. 21. In both cases the only significant differences between the 4 nitrogen treatments occurred in the May and June preharvests and were most likely the result of the March application of ammonium sulphate; the effect was an increase in the recoveries of both nutrients following this application.

The actual amounts of phosphate found in the crop during its first year of growth were under 80 pounds per acre. The maximum amounts were found in the crop harvested at 17½ months; these were under 175 pounds, and when considered in relation to the millable cane tonnage harvested make it appear that if the crop can get hold of one pound of P_2O_5 for each ton of millable stalks it will produce, this amount should be adequate, for this cane variety.

The large potash recoveries are at first glance somewhat staggering but it must be remembered that they include the potash in the green leaves and tops as well as in the stalks. The actual amounts average about 3 times the amounts of nitrogen that were found in the dry weights at consecutive harvests, and about seven times the amounts of phosphate.

The uptake of potash was in many respects similar to that of nitrogen, *i.e.,* it continued to be fairly uniform after the crop was well under way, although the July drop in nitrogen was not paralleled in potash. Like both nitrogen and phosphate, the potash recoveries in the final harvest at 20½ months were less than those found at 17½ months, and the greatest decreases were in Treatment D which had received the largest amount of nitrogen, and least from Treatments X and A. The best crops took up approximately 6 pounds of potash for each ton of millable stalks they produced.

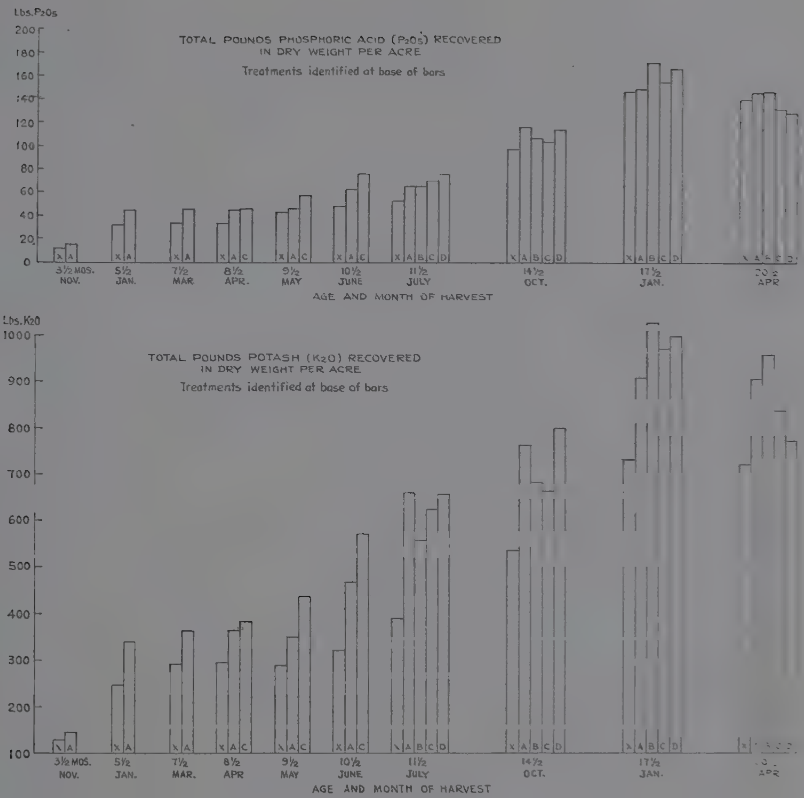

Fig. 21

Nitrogen Correlation

Between Per Cent Nitrogen in Leaf-punch Samples and Per Cent Nitrogen in Total Dry Weight:

There may be an interesting story from a study made of the correlation between the percentage of nitrogen in the leaf-punch samples and the corresponding percentage in the total dry weight. This study indicates certain practical limitations to the usefulness of leaf-punch or other percentage data, and may also be why we do not yet feel as confident about relying upon plant composition figures to indicate nutrient needs for sugar cane as some workers do for other crops. As previously mentioned our big problem is to find out whether our cane crop will need *more nitrogen* at a rather specific time and *after it has already been given a moderate amount;* thus we will seldom have cane with the low nitrogen content which is found in cane crops that have received little or no nitrogen fertilizer at all. This makes it exceedingly difficult for percentage figures for nitrogen in some portion of a cane crop to be sufficiently different as to be positively identified as high or low at a specific time, and both the age of the crop and its associated tonnage can further complicate the interpretation.

In Table V it will be noted that the effect of age, which in this case is inseparably combined with total dry weight, had an influence on the percentage composition of both leaf and total dry weight, for in spite of the fact that more nitrogen was applied to certain plots in March and again in June, the true average percentages found in all plots continued to decrease.

TABLE V

PER CENT NITROGEN IN LEAF-PUNCH AND IN TOTAL DRY WEIGHT AND ITS CORRELATION

Age	Month of sampling	True average—all plots: Per cent N in leaf	True average—all plots: Per cent N in total dry wt.	Correlation coefficient (r): With all 35 plots	Correlation coefficient (r): Without 3 zero N plots
7½	March	1.74	.515	$+.76\mp.07$	$+.22\mp.17$
8½	April	1.53	.423	$+.64\mp.10$	$+.26\mp.16$
9½	May	1.43	.401	$+.57\mp.11$	$+.25\mp.16$
10½	June	1.37	.368	$+.74\mp.08$	$+.22\mp.17$
11½	July	1.38	.312	$+.79\mp.06$	$+.31\mp.16$

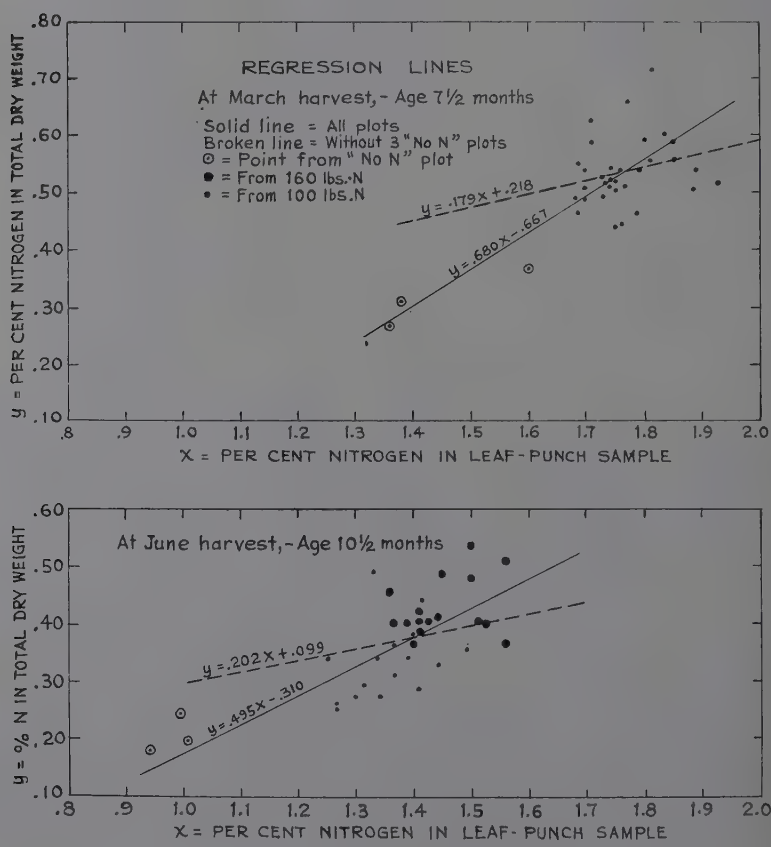

Fig. 22

The percent N in the leaf-punch samples was positively correlated with the per cent N in the total dry weight when the difference in the amount applied was a difference between zero and 100 pounds, or between zero and 160 pounds. But the dominant influence of the zero nitrogen plots is seen by the fact that when only 3 zero nitrogen plots are omitted from the correlation study, the remaining 32 plots fail to show significant correlation coefficients, in spite of the fact that different nitrogen treatments are involved after the March harvest. This is nicely shown by the regression lines in Fig. 22; without the 3 points from the zero nitrogen plots, the prediction of per cent nitrogen in the total dry weight on the basis of the percentage found in the leaf-punch samples would be quite unreliable.

Weather Relationships

Among other things needed to make our search for guidance in nitrogen fertilization more fully complete are studies of nitrogen utilization under different conditions of sunlight and temperature. Unfortunately our present investigation did not include these variables. Hence the best we can do here is to record the basic weather measurements made at Waipio while our crop was growing, and thereafter to study certain relationships between them and the response made especially by Treatment B which eventually proved the most efficient sugar producer. Therefore the basic data have been prepared by dividing the crop into six growth periods, each except the first being periods of 3 months, and recording the yields and the corresponding weather measurements during these 6 periods:

TABLE VI

BASIC YIELD AND WEATHER DATA

			(1) Increase in yields—tons/acre—avg. of 8 "B" plots				
Growth period	Dates	Age (mos.)	Green wt.	Dry wt.	Total sugars	TCA	TSA
1	8/1 to 1/13	0– 5½	44.18	8.86	2.088	25.78	.25
2	1/14 to 4/14	5½– 8½	16.20	6.09	4.063	18.28	3.67
3	4/15 to 7/14	8½–11½	36.96	9.41	3.728	33.06	2.57
4	7/15 to 10/13	11½–14½	45.51	8.96	3.334	44.00	.53
5	10/14 to 1/12	14½–17½	45.00	14.91	9.124	45.14	7.78
6*	1/13 to 4/20	17½–20½	—14.18	1.80	2.249	—8.27	4.05

(2)	Weather measurements						Avg. wind velocity m.p.h.
	Gram calories	Hours of sunshine	Day-degrees	Avg. temperature Min.	Avg. temperature Max.	Range in temperature	
1	73,608	1,139	2,426	67.2°	84.0°	16.8°	5.65
2	41,957	742	978	61.20°	80.2°	19.0°	6.22
3	54,454	829	1,457	65.7°	86.0°	20.3°	6.01
4	48,666	722	1,692	68.9°	88.6°	19.7°	5.60
5	36,068	449	1,203	63.0°	83.2°	20.2°	5.25
6	46,327	348	1,220	61.1°	82.4°	21.3°	6.06

* Drying off.

TABLE VII

SUNLIGHT AND TEMPERATURE UTILIZATION (BY TREATMENT B)

Growth period	Tons total green wt. per acre per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	Tons total dry wt. per acre per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	Tons total sugars per acre per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees
1	.600	3.878	18.211	.120	.778	3.652	.028	.183	.861
2	.386	2.183	16.564	.145	.821	6.227	.097	.548	4.154
3	.679	4.458	25.367	.173	1.135	6.458	.068	.450	2.559
4	.935	6.303	26.897	.184	1.241	5.296	.069	.462	1.970
5	1.248	10.022	37.406	.413	3.320	12.394	.253	2.032	7.584
6	(Loss)	(Loss)	(Loss)	.039	.517	1.475	.049	.646	1.843

Growth period	Tons millable cane per acre per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	Tons comml. sugars per acre per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees
1	.350	2.263	10.627	.003	.022	.103
2	.436	2.464	18.691	.087	.495	3.753
3	.607	3.988	22.690	.047	.310	1.764
4	.904	6.094	26.005	.011	.073	.313
5	1.252	10.053	37.523	.216	1.733	6.467
6	(Loss)	(Loss)	(Loss)	.087	1.163	3.320

From Table VI we have prepared Table VII to show the relative efficiency of temperature and sunlight received during the 6 growth periods selected. Though perhaps somewhat foreign to the immediate objective of our nitrogen study, we cannot let these data pass without a short comment.

Sunlight energy, as measured in gram calories on a pyroheliometer, apparently had a very different degree of efficiency during these 6 growth periods, being particularly effective on adequately fertilized cane between October and January when the crop was 14½ to 17½ months old; this same superiority was also found for the unit hours of sunshine and also for day-degrees, both of which with a few exceptions show a good relationship with the gram calories. Whether this superior utilization of sunlight energy in the fifth growth period is the effect of age or time of year or their interaction, only further research can tell, and just whether this effect could be changed by nitrogen applications will remain an open question until a more extensive and comprehensive study is made.

Some Interesting Ratios

We have searched the data obtained in this study for such enlightening relationships as may be found, and several of these have been recorded hereafter as specific ratios.

1. Ratio of Per Cent Total Sugars to Per Cent Nitrogen in Total Dry Weight:

First we made a study of the relationship between the total nitrogen and sugar percentages in the total dry matter harvested. We have one group of 32 analyses made from cane 3½ months old that was grown on plots which had received 40 pounds of nitrogen two months previously which shows a total sugar concentration that averages only 10 times the concentration of nitrogen at this age.

A second and a third group from these same 32 plots, harvested in January and March after all had been supplied with 100 pounds of nitrogen per acre, show average ratios of per cent sugars to per cent nitrogen of 29 to 1 and of 65 to 1, respectively. Further harvests in April, May, and June from 16 of these same

plots which had still received only 100 pounds of nitrogen fertilizer showed that these same ratios had been increased to 102, 115, and 124 respectively.

A more specific comparison of the ratios of per cent sugar to per cent nitrogen from the cane of 8 replicates of Treatments A and B, which had been similarly fertilized until after the June preharvests at 10½ months, reveals no significant differences:

RATIOS OF PER CENT SUGARS TO PER CENT NITROGEN IN TOTAL DRY WEIGHT

Treatment	At 3½ mos.	At 5½ mos.	At 7½ mos.	At 8½ mos.	At 9½ mos.	At 10½ mos.
A	9.7	28.3	63.1	103.2	119.6	123.5
B	9.3	28.9	63.0	101.4	111.5	124.5

Since Treatment B finally outyielded Treatment A, it would appear from these data that these high ratios at 10½ months indicated a high carbohydrates—low nitrogen status which was not optimum at this time, and the application of additional nitrogen was called for.

A similar comparison of Treatment C and D shows the following:

RATIO OF PER CENT SUGARS TO PER CENT NITROGEN IN TOTAL DRY WEIGHT

Treatment	At 3½ mos.	At 5½ mos.	At 7½ mos.	At 8½ mos.	At 9½ mos.	At 10½ mos.
C	10.3	30.5	68.3	88.2	83.4	93.6
D	11.0	30.1	67.3	81.6	88.4	96.5

At 7½ months (in March), these ratios were not significantly different from those for Treatments A and B. However, the March nitrogen applications to Treatments C and D were effective in lowering the per cent sugar to per cent nitrogen ratios, and at 10½ months in June they were considerably below the corresponding ratios for the A and B plots. Hence it would appear that a ratio of per cent sugar to per cent nitrogen of about 95, if found in the crop in June at the age of 10½ months, may indicate a desirable carbohydrate-nitrogen status at this time, since when still more nitrogen fertilizer was given to Treatment D in June, it was eventually shown to be an unnecessary application.

2. *Ratio of Pounds Nitrogen Per Acre Recovered in Crop to Tons Millable Cane Harvested:*

A figure for the number of pounds of nitrogen taken up by the crop with each ton of millable cane harvested has been a favorite measurement sought by some sugar men as a guide to the total amount which they should supply for any estimated tonnage. Thus the following summary was prepared:

POUNDS NITROGEN RECOVERED FOR EACH TON OF MILLABLE CANE HARVESTED

Treatment	At 14½ mos.	At 17½ mos.	At 20½ mos.
X	1.1	1.5	1.1
A	1.6	1.4	1.2
B	1.9	1.8	1.4
C	1.9	1.9	1.4
D	2.2	2.4	1.7

Again it must be pointed out (1) that these data do not include that nitrogen which is still unaccounted for in the roots and trash, and (2) that the nitrogen recovery at 20½ months was undoubtedly influenced by the loss of prematurely dehissed leaves during the drying-off period. But perhaps we can interpret the

figures liberally as showing that we need not plan total nitrogen applications for 32–8560 crops any greater than an amount which is 2 pounds for each ton of millable cane expected. By the same reasoning, this allowance should probably not be less than 1½ pounds of nitrogen for each expected ton of this cane variety.

3. Ratio of Per Cent Reducing Sugars to Per Cent Sucrose:

The influence of the different nitrogen treatments on the ratios of reducing sugars to sucrose is seen in the following data:

RATIO OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE

Treatment	March	April	May	June	July	Oct.	Jan.	April
X	.10	.08	.06	.06	.08	.06	.04	.02
A	.21	.11	.10	.12	.11	.14	.06	.03
B	...	...	...	...	.12	.20	.08	.04
C	...	.11	.11	.12	.15	.20	.07	.04
D	...	...	...	...	.15	.26	.09	.05

The increased ratios from the nitrogen-fertilized cane as found in October and the low ratios in January and April offer another way of indicating the changes in cane quality which were measured at these preharvests.

4. Ratio of Tons Total Sugars to Tons Total Dry Weight:

There were negligible differences in each successive harvest, in the ratio of total sugars to total dry weight, which were the effect from the different amounts of nitrogen applied. Furthermore, there was but little change in this ratio from successive harvests between March and October. Apparently the total sugar being manufactured in the cane plant kept in step with the total dry weight being produced during the first two-thirds of the growth period, but after this time the total sugars accumulated somewhat faster than the total dry weight. Such is our interpretation of the following data:

RATIO OF TOTAL SUGARS TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.12	.24	.38	.39	.40	.40	.40	.41	.46	.48
A	.11	.24	.35	.41	.41	.41	.41	.41	.46	.50
B	...	...	...	...	...	...	.41	.41	.46	.49
C	...	...	...	.41	.41	.41	.39	.39	.45	.49
D	...	...	...	...	...	...	.39	.38	.45	.51

5. Ratio of Tons Reducing Sugars to Tons Total Dry Weight:

This ratio of reducing sugars to the total dry weight was definitely affected when the cane crop was fertilized with nitrogen. Little change in this ratio occurred from the March fertilization within the subsequent 3 months, but at the time of the last 4 preharvests, the extra nitrogen given to Treatment C had increased its reducing sugars to dry weight ratio over Treatment A. Similarly the June applications of

fertilizers were responsible for increases in this ratio. These conclusions are drawn from the following data:

RATIOS OF REDUCING SUGARS TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.050	.068	.033	.028	.020	.022	.029	.022	.018	.011
A	.060	.091	.058	.040	.037	.042	.038	.049	.024	.012
B	....	....	....	....	....	....	.041	.062	.034	.016
C	....	....	....	.038	.038	.043	.049	.062	.027	.016
D	....	....	....	....	....	....	.049	.073	.038	.023

6. *Ratio of Tons Sucrose to Tons Dry Weight:*

To complete the picture, it will be seen from the following table that the nitrogen treatments which increased the ratio of reducing sugars to dry weight have at the same time decreased the ratio of sucrose to dry weight. Finally we note that at the last preharvest, differences in these sucrose to dry weight ratios from the fertilized canes, which had previously existed, were almost entirely ironed out.

RATIO OF SUCROSE TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.071	.164	.325	.340	.358	.355	.351	.366	.422	.446
A	.045	.137	.275	.353	.356	.354	.350	.343	.414	.466
B	....	....	....	....	....	....	.346	.318	.408	.451
C	....	....	....	.345	.350	.347	.323	.311	.405	.454
D	....	....	....	....	....	....	.326	.294	.390	.461

Discussion

Many of the data presented herein have already been adequately discussed but perhaps certain aspects should now be brought together to show just where our nitrogen problem stands at the moment.

Since soil analyses for both available and total nitrogen, which are made on samples taken before or subsequent to planting, apparently offer but little promise for specific guidance in nitrogen fertilization after the crop is well under way, we have turned to the cane crop for our answer.

Specific effects from differences in nitrogen applications—some desirable, others not so desirable—have been measured on the cane crop and sugar yields, and certain analyses have been found associated with these effects. An optimum recoverable sugar yield from 32–8560 plant cane harvested at 20½ months has been identified as the most likely result of known differences in nitrogen fertilization. Hence we may postulate that various measurement levels, which were associated with specific nitrogen treatments at the time of the March and the June fertilizations, offer an index of future nitrogen needs which we are seeking for the immediate crop under consideration. So we would point out what appear to have been optimum levels for certain measurements—levels above which an additional 60 pounds of nitrogen in our study was later proved uneconomical, and levels below which another 60 pounds of nitrogen was quite profitable. At the same time we emphasize that such levels as we found when the crop was only 7½ and 10½ months old were probably subjected to many separate influences and interactions which affected the final sugar recoveries 10 or 12 months later, so, much additional work will need to be done before these levels are sufficiently verified and established for the planter's guidance.

When our crop of 32–8560 cane had already been supplied with 100 pounds of nitrogen and had made normal development at 7½ months, we found that an additional 60 pounds of nitrogen were profitable for a 21-month crop under these conditions: (*a*) when only .53 per cent nitrogen was found in a sample of the total dry weight, (*b*) when the nitrogen in the leaf-punch samples was as low as 1.77 per cent, or (*c*) when the crusher juice from the stalks carried only .030 per cent nitrogen. Upper limits for cane at this stage of growth have not as yet been suggested by our studies.

When the crop was 10½ months old, we had what may be a suggestion for both the upper and the lower limits for these nitrogen measurements, but they are so close together that a highly accurate cane sampling technique is going to be needed if they are to be measured with confidence. Thus (*a*) with only .33 per cent nitrogen in the total dry weight at 10½ months, an extra 60-pound application was justified, but when .43 per cent nitrogen was found at this age, there was apparently no need for another nitrogen application; (*b*) with a leaf-nitrogen index at 1.36 per cent, another 60 pounds of nitrogen was called for but when this index was at 1.46 per cent, further nitrogen was found to be unnecessary; and (*c*) lower and upper limits of .018 per cent and .030 per cent respectively in the crusher juice at this age probably represented deficiencies and sufficiencies of nitrogen for another year of growth and sugar accumulation by this crop. Or perhaps the guide we want is indicated by the ratio of the per cent total sugars to per cent total nitrogen that was found in the dry weight at 10½ months; a ratio of approximately 125 to 1 indicated a need for additional nitrogen, whereas no economic increase in sugar yield was made from additional nitrogen when this ratio was 95 to 1.

Finally, we reiterate, that attempts to secure reliable and practical guidance in the use of nitrogen fertilizers, from indices of concentrations or of total amounts of nitrogen found in samples of sugar cane soils and crops, can be successful only if analyses and measurements are made from adequately replicated and truly representative samples. Furthermore, success in the interpretation of such data will await verification of their relationships with the most probable yields of recoverable sugar associated therewith.

The work is being continued. The ratoon crop is well under way and the plan of procedure will be quite similar to that of this plant crop. With certain levels of plant nitrogen content in mind, we seek their verification and further knowledge of their associations. Concurrently, a somewhat similar but more extensive study —with provision for more differentials in the applied nitrogen fertilizer—is underway at Makiki (Expt. 20 AxTN).

Acknowledgments

The writer has had the privilege of compiling, studying, and trying to interpret the measurement and analytical data which were obtained by the staffs of the several departments which cooperated in this nitrogen study. The crop was grown at Waipio under the careful supervision of F. C. Denison, B. K. Nishimoto and their assistants. Credit for the tremendous amount of work connected with obtaining and preparing the soil and the cane samples must go to R. E. Doty, L. R. Smith, A. H. Cornelison, A. Y. Ching, and their assistants (Y. Yamasaki and Y. Ikawa). The many soil analyses, the analyses of the nutrients in the crop samples and the

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References Cited

(1) Clements, Harry F., 1940. Integration of climate and physiologic factors with reference to the production of sugar cane. The Hawaiian Planters' Record, 44: 201–233.

(2) Cornelison, A. H., and Cooper, H. F., 1941. Further studies in nitrogen nutrition-time-of-application-of-nitrogen test. The Hawaiian Planters' Record, 45: 155–178.

(3) ————————————, 1940. Further studies in nitrogen nutrition-amounts-of-nitrogen test. The Hawaiian Planters' Record, 44: 273–308.

(4) Moir, Wm. W. G., 1930. The plant food problem. Reports Assn. Hawn. Sugar Technologists, pp. 175–203.

(5) Stewart, G. R., 1929. Periodic harvesting of H 109 cane at Oahu Sugar Company, Ltd. Reports Assn. Hawn. Sugar Technologists, pp. 199–220.

(6) Yuen, Q. H., and Hance, Francis E., 1939. Nitrogen in the cane leaf. The Hawaiian Planters' Record, 43: 163–207.

Appendix

Containing Summaries of Data and Statistical Measurements Thereof
(Measurements from the 3 "X" plots were not included in the statistical computations.)

TABLE 1

TOTAL GREEN WEIGHT—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	11.22	27.70	38.63	42.35	40.98	46.51	55.21	80.15	103.31	103.17
A	14.35	44.18	57.84	60.38	66.28	84.38	98.48	139.48	158.69	148.70
B	.....	......	......	......	......	......	97.34	142.85	187.85	173.67
C	.....	......	......	62.67	79.43	96.75	99.14	131.39	171.17	164.58
D	.....	......	......	......	......	......	107.66	150.88	188.02	163.59
S.D.*	3.22	8.04	7.61	11.45	13.26	16.92	16.76	33.61	24.94	28.84
C.V.*	22.5	18.2	13.2	18.6	18.2	18.7	16.6	23.8	14.1	17.7
M.d.r.*	.....	......	......	ns	9.7	ns	ns	ns	ns	ns

TABLE 2

PER CENT TOPS IN TOTAL GREEN WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.....	42.71	30.35	26.35	23.73	22.32	22.01	15.66	11.63	11.70
A	.....	40.97	31.71	26.88	23.13	20.08	18.92	15.17	11.79	8.46
B	.....	......	......	......	......	......	20.81	15.47	11.43	9.01
C	.....	......	......	25.94	24.53	21.63	21.75	14.64	11.04	8.26
D	.....	......	......	......	......	......	20.80	15.66	11.53	8.55
S.D.*	.....	2.01	2.48	2.50	1.89	2.03	1.56	1.59	1.49	1.33
C.V.*	.....	4.9	7.8	9.5	7.9	9.7	7.6	10.6	13.0	15.5
M.d.r.*	.....	......	......	ns	1.39	1.49	1.62	ns	ns	ns

* S.D. = Standard Deviation.
C.V. = Coefficient of variation.
M.d.r. = Minimum difference required for significance between Treatment A, B, C, and D only.
ns = Treatment effect not significant.

TABLE 3

PER CENT MOISTURE IN TOTAL GREEN WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	81.64	79.16	75.98	74.01	73.16	72.14	73.96	72.82	72.79	70.86
A	82.20	79.94	76.93	75.12	74.41	74.28	74.75	75.44	73.23	70.61
B	.....	......	......	......	......	......	74.96	76.67	74.42	71.29
C	.....	......	......	74.79	74.75	74.29	76.26	76.59	73.79	72.34
D	.....	......	......	......	......	......	76.27	77.91	75.03	72.70
S.D.	.....	.71	1.01	1.37	1.02	1.23	1.39	1.19	1.28	1.10
C.V.	.....	.09	1.3	1.8	1.4	1.7	1.8	1.6	1.7	1.5
M.d.r.	.....	......	......	ns	ns	ns	1.44	1.25	ns	1.14

TABLE 4

TOTAL DRY WEIGHT—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	2.06	5.77	9.28	10.94	11.00	12.88	14.37	21.79	27.71	29.94
A	2.55	8.86	13.37	14.95	16.96	21.68	24.81	34.31	42.33	43.77
B	.....	......	......	......	......	......	24.36	33.32	48.23	50.03
C	.....	......	......	15.83	20.11	24.79	23.48	30.79	44.80	45.59
D	.....	......	......	......	......	......	25.57	33.72	46.87	44.82
S.D.	.54	1.62	1.91	3.01	3.57	4.11	4.12	9.06	6.80	9.13
C.V.	21.2	18.3	14.3	19.6	19.3	17.7	16.8	27.4	14.9	19.8
M.d.r.	.....	......	......	ns	2.61	3.02	ns	ns	ns	ns

TABLE 5

PER CENT REDUCING SUGAR IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	4.999	6.694	3.349	2.654	1.996	2.189	2.795	2.243	1.721	1.027
A	5.794	9.115	5.760	3.990	3.641	4.204	3.866	4.904	2.334	1.219
B	.....	......	......	......	......	......	4.132	6.300	3.474	1.734
C	.....	......	......	3.894	3.817	4.284	4.913	6.288	2.741	1.614
D	.....	......	......	......	......	......	4.948	7.606	3.672	2.338
S.D.	.890	.674	.692	.939	.959	.725	.984	1.298	.732	.652
C.V.	15.4	7.4	12.0	23.8	25.7	17.1	22.0	20.7	24.0	37.8
M.d.r.	.....	......	......	ns	ns	ns	ns	1.349	.761	.678

TABLE 6

PER CENT SUCROSE IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	6.986	16.375	32.345	34.239	35.878	35.869	35.314	36.683	42.264	44.374
A	4.548	13.636	27.738	35.584	35.704	35.485	34.967	34.364	41.540	46.556
B	.....	......	......	......	......	......	34.602	31.589	40.721	45.063
C	.....	......	......	34.513	35.027	34.841	32.362	30.871	40.392	45.175
D	.....	......	......	......	......	......	32.584	29.254	39.111	46.334
S.D.	.722	1.315	1.525	2.052	1.917	1.573	2.261	3.091	1.705	2.641
C.V.	15.8	9.7	5.5	5.8	5.4	4.5	6.7	9.8	4.2	5.8
M.d.r.	.....	......	......	ns	ns	ns	ns	ns	ns	ns

TABLE 7

PER CENT TOTAL SUGARS IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	12.353	23.932	37.462	38.695	39.713	39.946	39.968	40.857	46.209	47.737
A	10.581	23.469	34.900	41.444	41.223	41.556	40.686	41.077	46.061	50.219
B	......	......	......	......	......	......	40.555	39.553	46.338	49.180
C	......	......	......	40.236	40.725	40.927	38.993	38.778	45.259	49.092
D	......	......	......	......	......	......	39.247	38.401	44.841	51.101
S.D.	1.06	1.399	1.649	2.388	1.733	1.570	1.891	2.484	1.922	2.849
C.V.	10.0	6.0	4.7	5.9	4.2	3.8	4.7	6.3	4.2	5.7
M.d.r.	......	......	......	ns	ns	ns	ns	ns	ns	ns

TABLE 8

PER CENT NITROGEN IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.866	.503	.311	.244	.243	.207	.172	.172	.251	.159
A	1.048	.797	.534	.406	.358	.335	.254	.276	.236	.185
B	......	......	......	......	......	......	.309	.341	.314	.231
C	......	......	......	.475	.474	.431	.365	.346	.329	.234
D	......	......	......	......	......	......	...372	.427	.413	.274
S.D.	.127	.064	.055	.055	.064	.064	.032	.045	.059	.026
C.V.	12.0	7.5	9.3	11.4	14.5	15.7	11.1	12.7	18.3	11.3
M.d.r.	......	......	......	.041	.046	.046	.035	.046	.062	.027

TABLE 9

PER CENT P_2O_5 IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.307	.275	.191	.164	.196	.185	.180	.223	.263	.239
A	.304	.254	.170	.148	.136	.141	.130	.174	.178	.171
B	......	......	......	......	......	......	.140	.163	.178	.148
C	......	......	......	.146	.145	.152	.150	.171	.173	.148
D	......	......	......	......	......	......	.150	.167	.175	.143
S.D.	.024	.015	.014	.012	.010	.011	.026	.019	.018	.020
C.V.	7.9	5.9	8.2	8.2	7.8	7.5	18.6	11.2	10.2	13.1
M.d.r.	......	......	......	ns	.008	.008	ns	ns	ns	.021

TABLE 10

PER CENT K_2O IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	2.755	2.181	1.568	1.363	1.330	1.222	1.340	1.206	1.308	1.205
A	2.869	1.923	1.385	1.238	1.040	1.081	1.330	1.113	1.072	1.056
B	......	......	......	......	......	......	1.140	1.012	1.073	.959
C	......	......	......	1.222	1.080	1.149	1.360	1.064	1.071	.924
D	......	......	......	......	......	......	1.290	1.160	1.062	.847
S.D.	.226	.243	.263	.070	.151	.193	.138	.152	.181	.173
C.V.	7.9	12.6	19.0	5.7	14.2	17.3	10.8	13.8	16.9	18.3
M.d.r.	......	......	......	ns	ns	ns	.14	ns	ns	ns

TABLE 11

REDUCING SUGARS—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.103	.393	.307	.305	.220	.282	.415	.486	.508	.327
A	.153	.829	.771	.599	.625	.904	.953	1.688	1.026	.528
B	......	......	......	......	......	......	.999	2.063	1.626	.819
C	......	......	......	.609	.755	1.064	1.155	1.896	1.217	.751
D	......	......	......	......	......	......	1.265	2.452	1.763	1.031
S.D.	.047	.176	.123	.141	.180	.205	.298	.446	.380	.272
C.V.	32.7	21.7	15.6	23.4	26.1	20.3	27.4	22.2	27.0	34.8
M.d.r.	......	......	......	ns	ns	.149	ns	.464	.395	.291

TABLE 12

SUCROSE—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.147	.948	3.013	3.720	3.943	4.573	5.038	7.982	11.705	13.342
A	.114	1.215	3.686	5.275	6.038	7.664	8.678	11.777	17.539	20.410
B	......	......	......	......	......	......	8.436	10.592	19.676	22.573
C	......	......	......	5.467	7.042	8.613	7.577	9.575	18.143	20.704
D	......	......	......	......	......	......	8.329	9.922	18.258	20.643
S.D.	.036	.301	.549	1.044	1.353	1.367	1.449	3.298	2.897	4.202
C.V.	31.6	24.8	14.9	19.4	20.7	16.8	17.6	31.5	15.7	19.9
M.d.r.	......	......	......	ns	.992	ns	ns	ns	ns	ns

TABLE 13

TOTAL SUGARS—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.257	1.390	3.484	4.220	4.365	5.095	5.718	8.887	12.829	14.371
A	.272	2.088	4.644	6.151	6.981	8.972	10.091	14.084	19.488	22.009
B	......	......	......	......	......	......	9.879	13.213	22.337	24.586
C	......	......	......	6.365	8.174	10.123	9.134	11.973	20.314	22.517
D	......	......	......	......	......	......	10.033	12.896	20.982	22.755
S.D.	.079	.460	.670	1.168	1.491	1.575	1.649	3.697	3.230	4.488
C.V.	28.3	22.0	14.4	18.7	19.7	16.5	16.9	28.3	15.5	19.5
M.d.r.	......	......	......	ns	1.091	1.151	ns	ns	ns	ns

TABLE 14

MILLABLE CANE—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		15.91	26.91	31.19	31.22	35.96	43.01	67.60	91.98	91.22
A		25.78	39.44	44.06	51.05	67.37	79.91	119.67	140.14	136.26
B		......	......	......	......	......	77.12	121.12	166.26	157.99
C		......	......	46.46	59.96	76.45	77.51	111.12	152.33	151.15
D		......	......	......	......	......	85.44	128.73	166.07	149.60
S.D.		5.74	6.28	8.74	10.48	13.30	13.37	28.57	21.65	26.70
C.V.		22.3	15.9	19.3	18.5	18.5	16.7	23.8	13.9	17.9
M.d.r.		......	......	ns	7.7	ns	ns	ns	ns	ns

TABLE 15

COMMERCIAL SUGAR—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		.51	2.10	3.01	3.28	3.58	3.81	6.22	9.41	11.07
A		.25	2.40	3.92	4.85	5.91	6.46	8.65	14.41	16.23
B		......	......	......	......	......	6.49	7.02	14.80	18.85
C		......	......	4.27	5.59	6.78	6.03	5.93	14.24	17.12
D		......	......	......	......	......	6.19	5.79	13.83	15.85
S.D.		.16	.47	.84	1.26	1.15	1.35	2.11	2.39	3.84
C.V.		64.0	19.6	20.2	24.3	18.1	21.4	31.0	16.7	22.6
M.d.r.		......	......	ns	ns	.85	ns	2.18	ns	ns

TABLE 16

YIELD PER CENT CANE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		3.2	7.8	9.7	10.5	10.1	9.1	9.1	10.4	12.0
A		0.9	6.1	9.0	9.5	8.8	8.2	7.3	10.4	11.9
B		......	......	......	......	......	8.4	5.9	8.9	11.9
C		......	......	9.2	9.3	8.9	7.2	5.4	9.3	11.3
D		......	......	......	......	......	7.2	4.4	8.3	10.6
S.D.		.5	.8	.7	1.1	.9	1.3	1.1	.6	1.2
C.V.		50.0	13.4	7.3	11.8	11.0	16.8	19.3	6.6	10.3
M.d.r.		......	......	ns	ns	ns	ns	1.1	.6	ns

TABLE 17

NITROGEN IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	35.1	58.1	57.4	53.9	52.6	54.1	50.9	75.7	138.5	96.1
A	53.2	140.2	143.2	120.5	119.7	144.4	125.5	188.8	201.8	159.9
B	......	......	......	......	......	......	150.5	224.1	302.1	228.0
C	......	......	......	148.6	187.3	214.1	170.7	209.7	296.1	212.1
D	......	......	......	......	......	......	187.5	285.9	394.0	247.7
S.D.	10.2	18.7	26.0	24.5	24.1	42.6	32.2	62.1	78.1	44.1
C.V.	19.0	13.3	18.1	18.2	15.7	23.8	20.3	27.4	26.2	20.8
M.d.r.	......	......	......	17.9	17.6	31.2	33.5	64.6	81.2	45.8

TABLE 18

P_2O_5 IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	12.5	31.5	35.4	35.1	42.6	48.9	52.8	98.9	148.3	141.5
A	15.5	44.8	45.3	44.6	46.2	61.5	65.4	118.8	149.7	147.0
B	......	......	......	......	......	......	64.8	108.4	170.9	147.7
C	......	......	......	45.7	58.4	75.8	70.7	105.5	155.1	133.5
D	......	......	......	......	......	......	76.3	114.8	166.9	129.7
S.D.	3.0	7.8	6.7	9.9	11.0	15.6	17.0	34.3	27.6	28.1
C.V.	19.4	17.4	14.7	21.9	21.1	22.7	24.5	30.7	17.1	20.2
M.d.r.	......	......	......	ns	8.1	11.4	ns	ns	ns	ns

TABLE 19

K_2O IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	112.4	249.0	291.0	292.5	286.4	322.2	388.8	532.7	730.5	721.2
A	146.2	338.6	366.5	367.1	349.6	468.6	656.9	762.9	902.8	905.2
B	......	......	......	......	......	......	555.9	677.2	1024.7	955.9
C	......	......	......	381.4	435.3	569.5	623.9	658.2	968.0	836.7
D	......	......	......	......	......	......	651.2	796.8	990.0	771.7
S.D.	36.1	77.2	64.6	92.5	93.4	134.9	110.5	229.7	186.7	203.4
C.V.	24.7	22.8	17.6	24.7	23.8	26.0	17.8	31.7	19.2	23.5
M.d.r.	......	......	......	ns	68.3	98.7	ns	ns	ns	ns

TABLE 20

PER CENT NITROGEN IN LEAF-PUNCH SAMPLES

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	1.76	1.71	1.45	1.16	1.03	.98	.97	1.15	1.18	.90
A	1.99	1.96	1.77	1.55	1.44	1.36	1.31	1.35	1.40	1.06
B	......	......	......	......	......	......	1.43	1.46	1.51	1.17
C	......	......	......	1.58	1.51	1.46	1.41	1.45	1.54	1.16
D	......	......	......	......	......	......	1.52	1.54	1.62	1.20
S.D.	.11	.06	.06	.04	.04	.06	.05	.06	.07	.06
C.V.	5.5	3.1	3.4	2.6	3.4	4.3	3.5	4.3	4.6	5.2
M.d.r.	......	......	......	.03	.03	.05	.05	.07	.07	.06

TABLE 21

PER CENT NITROGEN IN CRUSHER JUICE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		.011	.011	.009	.009	.008	.006	.006	.009	.009
A		.036	.030	.025	.023	.018	.013	.011	.012	.014
B		......	......	......	......	......	.017	.018	.018	.019
C		......	......	.034	.035	.030	.022	.019	.019	.020
D		......	......	......	......	......	.023	.027	.026	.027
S.D.		.008	.007	.009	.008	.008	.004	.004	.003	.004
C.V.		22.2	26.7	31.0	27.6	30.4	21.1	21.0	15.8	18.5
M.d.r.		......	......	.006	.006	.006	.004	.004	.003	.004

TABLE 22

PER CENT CHLOROPHYLL IN GREEN-LEAF BLADES

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.071	.086	.085	.084	.062	.064	.062	.086	.098	.049
A	.087	.124	.120	.101	.091	.088	.089	.102	.123	.064
B	......	......	......	......	......	......	.099	.116	.123	.075
C	......	......	......	.108	.103	.098	.089	.119	.132	.077
D	......	......	......	......	......	......	.091	.123	.143	.078
S.D.	.001	.002	.001	.008	.008	.009	.012	.017	.018	.010
C.V.	11.9	13.0	9.9	7.3	8.6	10.3	13.0	14.8	13.4	13.2
M.d.r.	......	......	......	.006	.006	.007	ns	ns	ns	.010

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 16, 1942 TO SEPTEMBER 15, 1942

Date	Per pound	Per ton	Remarks
June 15 - Sept. 15, 1942........	3.74¢	$74.80	Philippines

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